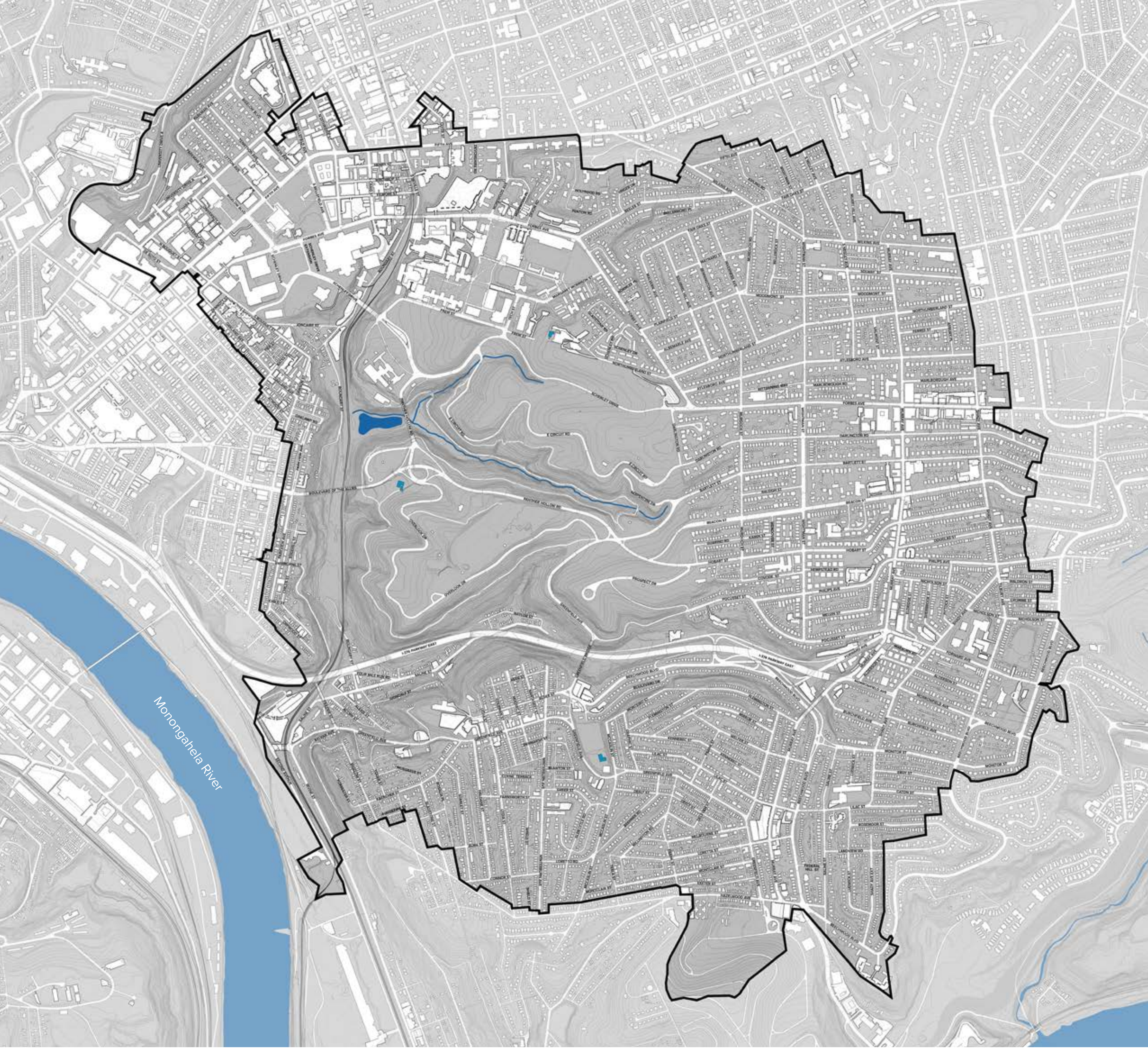

Four Mile Run

Stormwater Improvement Project

PGH2O Pittsburgh Water & Sewer Authority

Watershed Expansion Memorandum

Final Revision on 30 August 2019

Pittsburgh Water & Sewer Authority

This interim document was created as part of the Pittsburgh Water and Sewer Authority's Four Mile Run Stormwater Improvement Project. The Watershed Expansion Team (WET), comprised of evolveEA, Ethos Collaborative, and eDesign Dynamics, prepared this document as sub-consultants to Civil and Environmental Consultants, the project lead. Mott MacDonald, also sub-consultant to CEC, generated a separate report on SWMM model results to which this memorandum makes reference.

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Revised 30 August 2019

Contents

Cover Graphic: Map of impervious areas shed-wide.

Introduction

"Pittsburgh owes it existence to the meanders and confluence of three great American rivers. The Allegheny, Monongahela, and the Ohio Rivers are a point of pride and are integral to the City's identity. As the city continues its historic transition from a riverfront industrial superpower to an education and research mecca, the quality of our rivers and riverfronts is of paramount importance."

PWSA Green First Plan, Appendix F, Page 5, 2016

The 4MR Project Premise

In 2016, Pittsburgh Water and Sewer Authority (PWSA) created the Green First Plan, its strategy to achieve combined-sewer overflow (CSO) compliance by developing a high performance network of green stormwater infrastructure. The Plan looked at integrating green infrastructure within the unique urban contexts of six of the largest sewersheds within PWSA's combined sewer system (CSS): A-41, A-42, M-16, M-19, M-29, and O-27. The Plan's recommendations for M-29, the sewershed associated with the historic Four Mile Run, form the basis for the Four Mile Run (4MR) Stormwater Improvement Project.

The Design Team, led by CEC, is tasked with developing the 30% plans for the transformation and daylighting of Four Mile Run and Panther Hollow Lake within Schenley Park. The intent of the design is to separate stormwater runoff and stream flow from the combined sewer system and convey it so that it discharges directly to the Monongahela River.

Hydrologic components within the Park will be engineered to imitate natural systems and will be expected to perform the following functions:

- Surface **conveyance** of wet and dry weather flows to a new point of discharge to open water at the Monongahela River;
- **Detention** and flow regulation to "flatten the hydrograph" and reduce peak flows within the system;
- **Flood management** during peak events so that developed areas are less frequently inundated; and
- **Water quality** measures to meet discharge standards set by the Clean Water Act and MS4 regulations.

These functions are crucial to meeting PWSA's CSO mitigation goals for the M29 sewershed. Additionally, the project's location within Schenley Park requires consideration of additional design priorities supported by the City's Department of Public Works, Department of Mobility and Infrastructure, the Pittsburgh Parks Conservancy, and other stakeholders in the sewershed. The full extent of public priorities is yet to be established, but generally addresses the need for enhanced Park amenities and habitat benefits. While these priorities and subsequent designs are not part of the current scope-of-work, it is the intent of PWSA and the Design Team to anticipate opportunities for cost-sharing and mutual benefit.

Facing Graphic: The Four Mile Run future stream corridor.
Enhanced image from Google Earth.

Introduction (continued)

Assessment of Expansion Opportunity

Separate conveyance of stormwater runoff to the river will reduce combined sewer overflows (CSOs) and mitigate flooding issues within the Four Mile Run neighborhood and elsewhere. The current scope-of-work involves design interventions within Schenley Park, including daylighting of the stream within Junction Hollow, restoration of streams within the park, and improvements to Panther Hollow Lake. The expectation, however, is that runoff from developed areas outside of the Park and within the watershed will in the future be diverted toward surface drainage networks within the Park, without discharging to combined sewers.

Ethos Collaborative, evolveEA and eDesign Dynamics (the Watershed Expansion Team or WET) developed a possible conveyance approach from upstream areas so that the constructed stream networks within the Park can be located and sized for adequate management of peak wet-weather flows. Hydrologic features within the Park built as part of the Four Mile Run Stormwater Improvement project can enable future expansion of a green infrastructure conveyance network throughout the watershed.

FIGURE 0.1

M-29 Four Mile Run Urban Design Framework Plan

Source: PWSA City-Wide Green First Plan, Figure 6-15

Building upon the Green First Plan

The Green First Plan built upon existing momentum around creating a day-lit stream through Junction Hollow to convey water from Panther Hollow Lake to the Monongahela River, roughly following the path of the historic Four Mile run. The Green First Plan also recommended that this new stream should become the backbone for stormwater conveyance from the developed neighborhoods around Schenley Park. It identified the Universities in Oakland and Bartlett Street in Squirrel Hill as being future expansions of the conveyance network, disconnecting stormwater from the combined-sewer network and conveying it to Four Mile Run instead.

This memorandum expands upon this strategy by looking at the opportunities for a conveyance network across the entire sewershed. Within each of 13 sub-catchment areas, this memorandum shows one possible scenario of networked conveyance infrastructure that could convey stormwater to Monongahela. Through this lens, the Watershed Expansion Team identified the topics that need further investigation to narrow the cone of uncertainty so that a well-prioritized conveyance-based plan can be implemented in this sewershed.

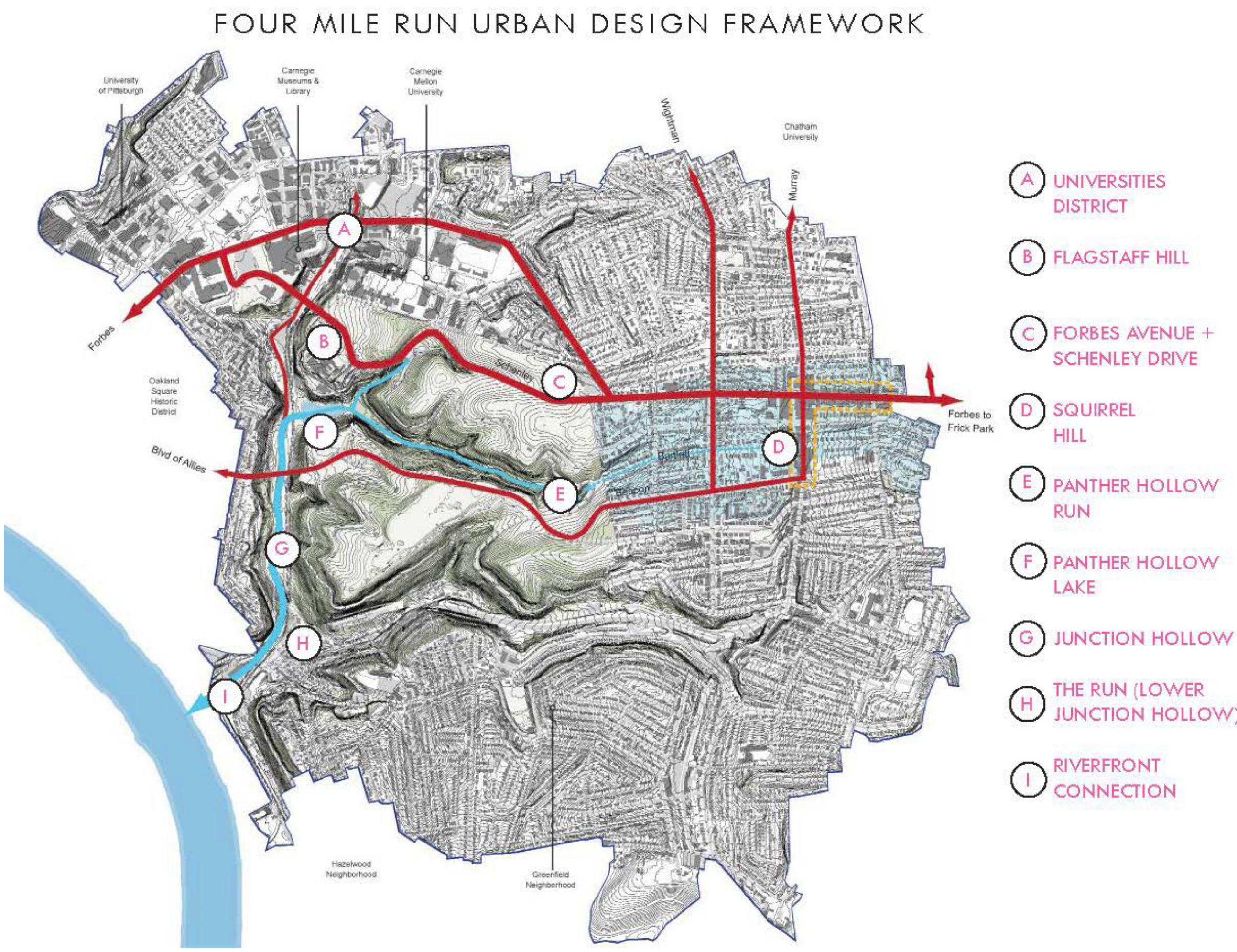
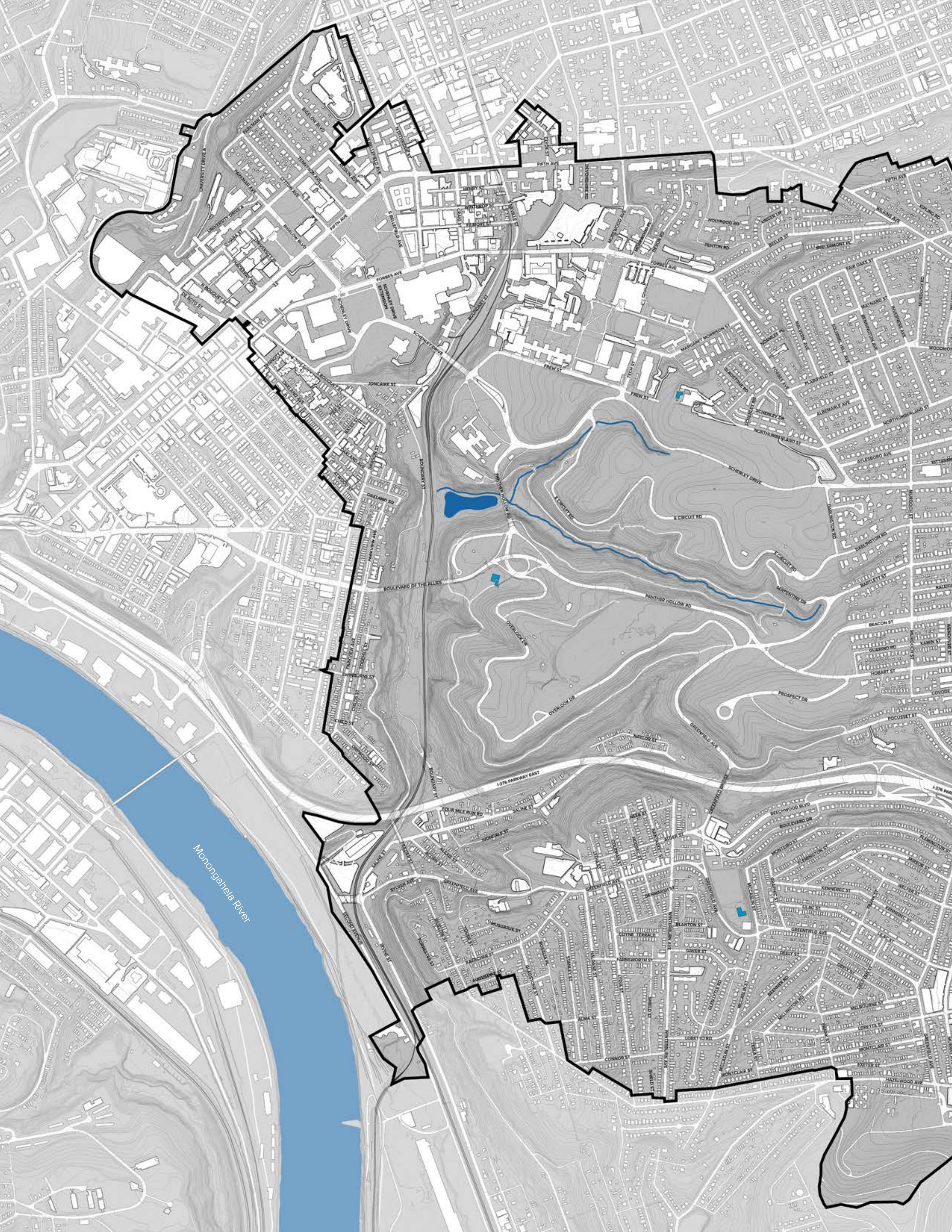


FIGURE 0.2

M-29 Four Mile Run Urban Design Framework Plan

Source: PWSA City-Wide Green First Plan, Figure 6-16



Monongahela River
FIFTH AVE
FORBES AVE
SCHENLEY DRIVE
FREW ST
BOULEVARD OF THE ALLIES
PANTHER HOLLOW RD
OVERLOOK DR
PROSPECT DR
GREENFIELD AVE
I-376 PARKWAY EAST
BEACON ST

1

Strategy for Expansion

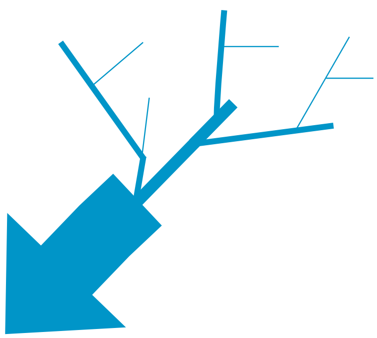
On-Site Management
Flow Separation
Surface Conveyance Networks
“Node” Capture and Detention
Park Connections
Case Studies

Map of shows impervious surfaces: buildings, streets, and parking lots.

Strategy for Expansion

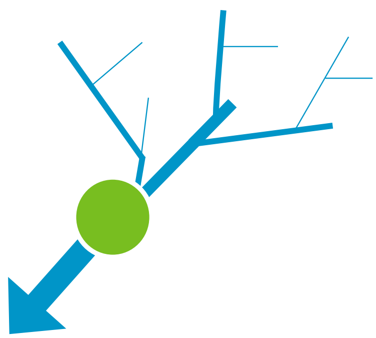
At this stage of design, the primary inputs needed to inform design of the stream and discharge network are peak stormwater flows and dry-weather base flows within each of the tributary areas in the Park, evaluated for a hypothetical time in the future when all phases of the watershed expansion effort are complete. While this early effort is not intended as a design exercise for stormwater separations within developed areas, some of the strategies and techniques for separation are needed in order to understand the likely operating conditions.

From the perspective of reducing the CSO events and localized flooding, the goal in M29 is to divert as much runoff as possible away from combined sewers for management in surface features. This strategy involves creating a distributed detention and conveyance network, that manages stormwater local to where it falls with small scale, scattered detention sites and curbside roadway conveyance. Several different practices that each contribute to the proper functioning of the entire system will be needed to create this distributed network.



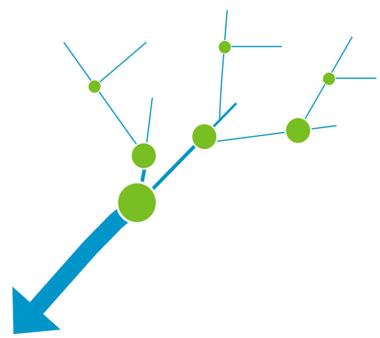
BIG CONVEYANCE

Manage the stormwater by building a large pipe or open channel to **CONVEY** it further downstream.



BIG DETENTION

Manage stormwater at a confluence point by **DETAINING** it and releasing at a lower flow rate.



NETWORKED CONVEYANCE WITH EMBEDDED DETENTION

Manage stormwater local to where it falls with smaller scale **DETENTION** sites embedded within a right-of-way **CONVEYANCE** network.

FIGURE 1.1 A drop shaft and tunnel boring machine in Washington, DC.
Source: Chesapeake Quarterly

FIGURE 1.2 A large stormwater detention facility.
Source: Delaware DOT

FIGURE 1.3 A bioswale in Pittsburgh, PA
Source: evolveEA

On-Site Management

While every parcel has its unique conditions, on-site management of runoff generated from impervious surfaces within the parcel should be implemented to meet current municipal standards for stormwater management. This involves enforcing code for new construction and promoting retrofit scenarios within properties that possess available space and an amenable landowner. Techniques include use of rain gardens, cistern storage (for reuse or release), reduction of impervious surface areas, green roofs, pervious pavements, etc. These practices should be sized to capture and manage runoff from a minimum of 1.5 inches of rainfall. Overflows or low-flow releases from these practices should be directed toward alternative (surface) conveyance networks that will be developed within (or adjacent to) the right-of-way (ROW).

Flow Separation

Wherever feasible to safely convey stormwater on the surface, existing storm connections to the combined sewers should be closed or disconnected. This includes disconnection of downspouts, closure of driveway drains or other area drains, and closure (or partial closure) of street inlets in areas that will become connected to the Monongahela River through the stormwater conveyance network. Larger impervious areas such as parking lots or extensive roofs will require special attention to avoid damage from high flows during peak events.

FIGURE 1.4

Roof runoff can be directed toward rain gardens integrated within the front or rear yard. Rain gardens can serve more than one property and, in many cases, can be allowed to overflow to the ROW.

Source: evolveEA

FIGURES 1.5

Most rooftops in the region connect to the sewer system. As part of this design, the team looked at opportunities to disconnect roof downspouts and driveway drains. The development of a surface conveyance network to new stormwater infrastructure provides homeowners with the opportunity to disconnect roofs and driveways from the combined sewer, where feasible. As entire areas become disconnected, it may become most feasible to create new piped connects for discharge directly to the street.

Source: University of Nebraska

Strategy for Expansion (continued)

New Surface Conveyance Networks

Several practices exist for retrofitting new surface (or near surface) conveyance networks within developed areas, such as connected bioswales, enhanced gutters and trench drains. These features can be connected or networked using isolated sections of dedicated storm sewers or other hybrid green/gray techniques. The most feasible and affordable option is to utilize ROW areas - streets, traffic medians and road verges - to create channels capable of managing contributing flows. Managing stormwater at the surface or in shallow conveyance systems is more cost-effective for rate payers and allows for Pittsburgh's topography to move water. These techniques, which are highly effective in areas with slopes greater than 2%, are currently under consideration by PWSA and DOMI for use at Wightman Park as part of a PWSA project led by Ethos Collaborative. This involves diversion of runoff from adjacent properties toward the ROW, as well as closure (or partial closure) of street inlets. Road verges can be excavated and planted to become depressed channels. Traffic medians can be modified or added to become receiving areas and conveyance pathways, often requiring regrading of the roadway to provide proper drainage. Most significantly, curbside conveyance can be greatly enhanced by ensuring an adequate roadway crown, repairing or replacing degraded curbs, and providing a narrow and slightly depressed channel adjacent to the curb.

Roadway crossings are an additional challenge which can be met with the use of trench drain crossings, modifications to the roadway geometry to include a "warped" depression at the intersection (also serving as a traffic calming measure), near-surface pipe installed over the roadway at grade and covered with asphalt to create a "speed bump," or bump-outs that capture runoff from the curbside for conveyance under the roadway and then discharge back to the curbside at a point downstream where the elevation permits it. A combination of these practices, configured for the specific conditions at each location, should be adequate to safely convey runoff on the surface for a distance of four to six blocks, depending on slope.

FIGURE 1.6

As stormwater runoff from more properties becomes disconnected from the sewer system, it becomes necessary to provide alternative conveyance systems that safely allow the runoff to drain toward a management zone. When urban streams are not available, these conveyance networks can be configured using vegetated swales or interconnected bioswale chains. Within the ROW, street gutters can be enhanced by creating a more sizable channel for conveying flows, allowing for inlet closures and diversion toward common points of collection.

Source: USACE National Flood Risk Management Program

"Node" Capture and Detention

Under full build-out, each of the surface conveyance networks will drain toward a "node" or point of capture that also possesses some volume for detention storage. These features can be surface ponds or subsurface detention structures, and will provide energy dissipation, sediment removal, and storage for flow regulation. Storage for flow regulation is an important feature of a secondary conveyance network as detention facilities can be used strategically to offset peak flows, thus preventing downstream conveyance pathways from becoming overwhelmed. This capability is elaborated on in **A.1 Controlling Peak Flows**.

Connecting to the Network

Each “node” will need to connect to the stormwater conveyance network, sometimes requiring the installation of new large-diameter pipes, depending on node location and size. The team sought innovative opportunities to reassign the use of redundant combined sewers for stormwater conveyance, or use of new pipe inserts to allow for contained conveyance of sanitary flows within the larger repurposed and existing combined sewers, which were sized to handle storm flows. Other solutions address specific land form conditions, such as the use of surface mounted pipes that lead down steep wooded hillsides or additional surface channels, especially within park areas.

Each of the separated sub-catchment areas connected by the above means should become ***individual projects phased to overall expand performance over time***. As runoff from more areas is separated and conveyed to the Park, more relief is provided to ALCOSAN’s interceptor system, reducing overflows at CSO outfalls and at points upstream that have historically released combined sewage within the streets and basements of the Four Mile Run community.

FIGURE 1.7

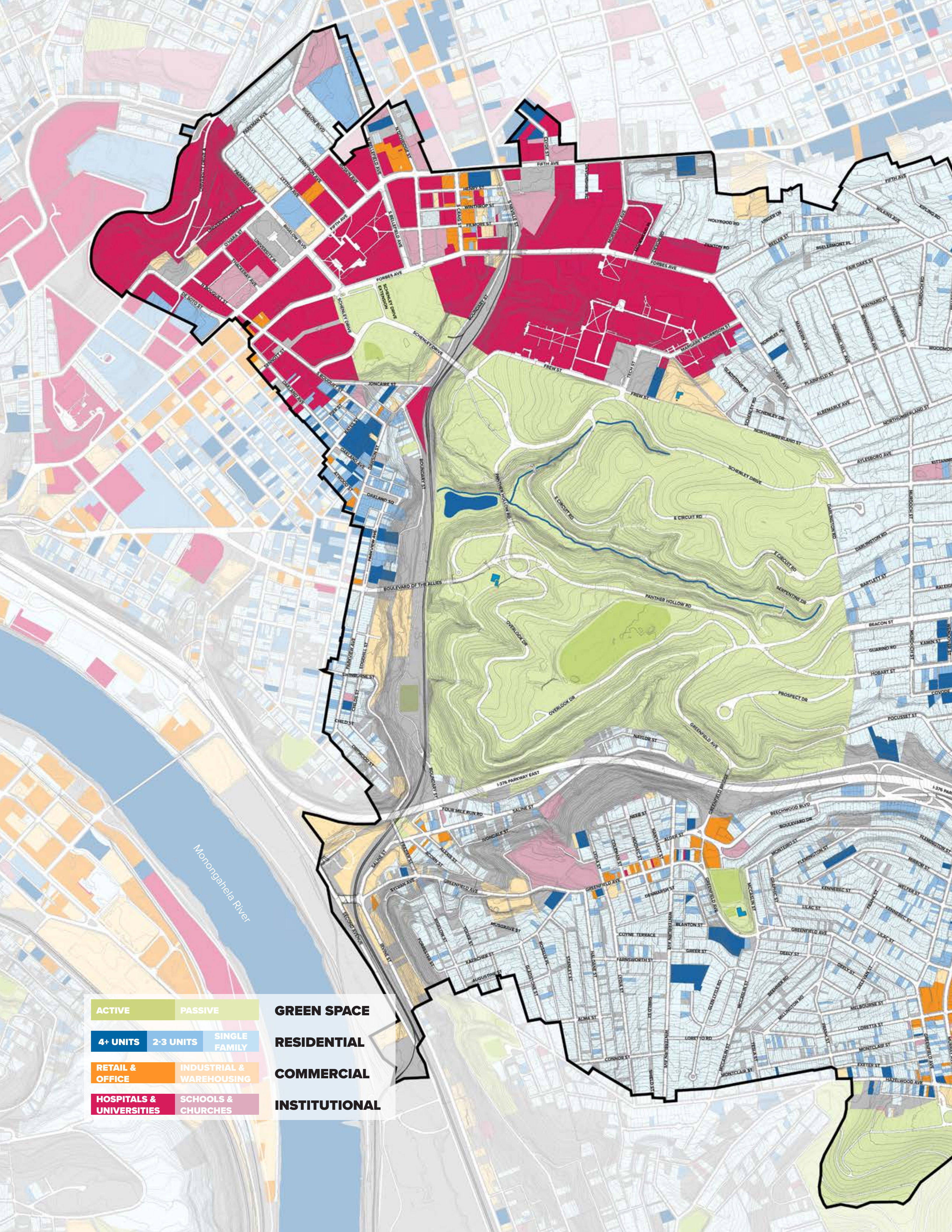
Multiple properties or structures can be allowed to drain toward one rain garden by redirecting runoff to the right-of-way, conveying along the curb-side, and capturing runoff from the street. The rain garden allows an opportunity for the water to infiltrate, but is also configured to both overflow and slowly drain to the sewer system.

Source: Burke Group

FIGURE 1.8

Stormwater collected from a neighborhood will frequently need to get across streets and down steep hillsides to reach the new stream network in the valley. Many of these techniques are “gray” in nature because of the high susceptibility to erosion, and the barriers presented by roads or other structures.

Source: Massachusetts Clean Water Toolkit


ACTIVE
PASSIVE
GREEN SPACE
4+ UNITS
2-3 UNITS
SINGLE FAMILY
RESIDENTIAL
RETAIL & OFFICE
INDUSTRIAL & WAREHOUSING
COMMERCIAL
HOSPITALS & UNIVERSITIES
SCHOOLS & CHURCHES
INSTITUTIONAL
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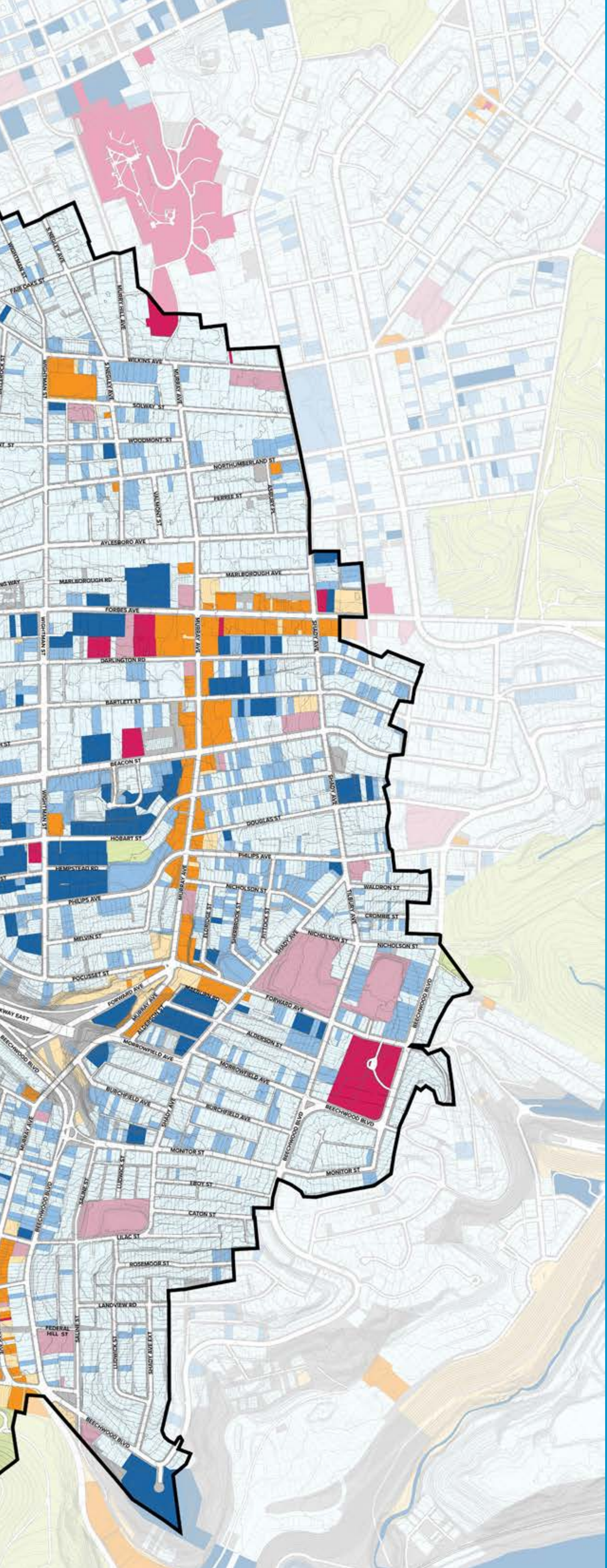

2

Watershed Expansion Estimation Methodology

Determining the Sub-catchment Areas
Estimating Costs
Estimating Performance
Assessing Cost-Effectiveness
Cost-Sharing Scenario

Map of shed-wide land uses.

Watershed Expansion Estimation Methodology

The M-29 Four Mile Run Sewershed

In broad terms, each neighborhood is fairly homogeneous in land use and disconnection strategy. Topography throughout the sewershed could allow for a gravity-based hybrid of green and gray infrastructure to convey stormwater to the Four Mile Run valley. Given that there not many vacant spaces within the neighborhoods where centralized green infrastructure projects can be built, the main opportunities for capturing and managing stormwater in this shed must be located within the right-of-ways. This is reflected in the types of infrastructure included in cost estimates.

South and Central Oakland are largely residential with attached and unattached residential units. This area is near to the project area and could be easily disconnected. North Oakland is largely institutional and is home to a sizable portion of the shed's impervious area. Because much of the property is under consolidated ownership, those institutions could be partners in connecting separated sewer areas to the Four Mile Run valley.

Squirrel Hill North is largely detached single family homes. There area a few opportunities within this neighborhood for site-based detention and release installations, including Wightman Park which is due for reconstruction. Connecting Squirrel Hill North to the

Table 2.1 Sub-catchment Areas

#	Area Name	Area (acres)	Impervious Area Percentage[i]	GIS-based Impervious Acres[ii]	Model-Equivalent Impervious Acres[iii]	Impervious Acres Managed[iv]	Management Ratio[v]
1	Project Catchment Area	457.4	15%	67.3	45.3[vi]	59[vii]	100%
2	Phipps Conservatory	16.0	33%	5.3	3.6	0	0%
3	South Oakland	25.2	43%	10.9	7.3	7.3	100%
4	Oakland	301.1	53%	158.3	106.7	40.5	38%
5	Carnegie Mellon	171.0	43%	74.1	50.0	22.0	44%
6	Forbes Avenue	101.5	35%	35.2	23.7	8.1	34%
7	Squirrel Hill North	215.9	36%	78.0	52.6	14.1	27%
8	Bartlett Street	187.3	43%	81.2	54.8	18.1	33%
9	Squirrel Hill South and Greenfield	627.8	39%	244.8	165.0	38.3	23%
10	Magee Field	95.2	38%	35.8	24.1	12.6	52%
11	Greenfield School	22.6	41%	9.2	6.2	3.7	60%
12	Greenfield Avenue	97.0	37%	36.3	24.5	10.1	41%
13	Irvine Street	52.4	28%	14.4	9.7	6.9	71%
	Summary	2370.3	36%	850.8	573.5	181.8	32%

i Based on GIS impervious acres.
ii GIS impervious acreage analysis takes into account buildings, parking lots, streets, and an estimate of sidewalks.
iii Impervious area based on GIS impervious acreage multiplied by 0.6741 to estimate the modeled impervious area.
iv Based on assumptions set forth for each zone in this chapter and given to the SWMM team as a set of marked sub-catchments in a shape file on 12 March 2019.
v Percentage of impervious acres that are managed given the assumptions in this chapter.
vi Estimated based on GIS impervious acreage multiplied by 0.6741. Thus this
vii Based on SWMM estimate of Impervious Area Redirected in a presentation by Mott MacDonald on 05 April 2019.

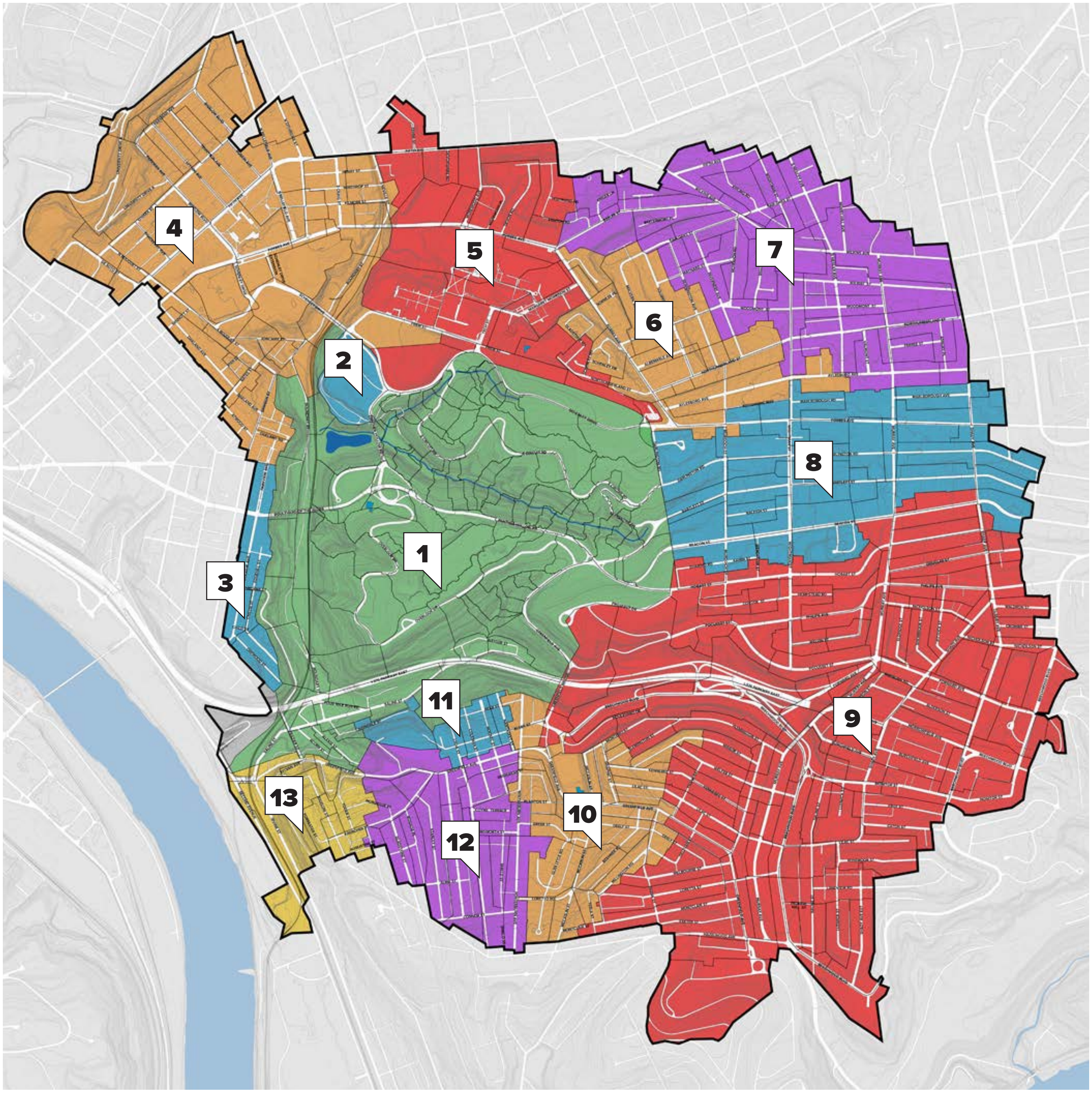

Figure 2.1 Map showing sub-catchment area groups.

Watershed Expansion Methodology (continued)

Four Mile Run valley would require strategic installation of major infrastructure under Carnegie Mellon's campus. The business case for such infrastructure is yet to be determined but preliminary modeling seems to show that the Four Mile Run project would not have the capacity on its own for these flows.

Squirrel Hill South has similar development patterns to Squirrel Hill North albeit with more multi-family housing and strong retail corridors on Forbes and Murray. Parts of Squirrel Hill South could connect to the top of Panther Hollow Run via conveyance along Bartlett Street. Other parts of Squirrel Hill South could connect to the Saline Street branch of Four Mile Run if a connection can be made along the Parkway East (I-376).

Greenfield is similarly developed to Squirrel Hill South and is could also connect to the Saline Street branch of Four Mile Run if a connection can be made along the Parkway East (I-376). Large parts of Greenfield could connect to Magee Field, a large opportunity for detention and slow release infrastructure.

Determining the Sub-catchment Areas

This analysis created sub-catchment areas by grouping ArcHydro catchment areas utilized in the SWMM analysis into larger groups that were reflective of major connection points to downstream receiving areas. These groupings also reflect areas where the stormwater management strategy is similar throughout the area.

Determining Impervious Acreage

The number of impervious acres in a given sub-catchment area was calculated based on available GIS data including buildings, parking lots, and streets. Sidewalk areas were also inferred from GIS geometry and included in this analysis. This differs from the model impervious acres which take into account that not all impervious surfaces reach the combined-sewer network and are adjusted to calibrate the model to rain gauge and flow meter data. In total, there are 851 GIS-based impervious acres and 574 model impervious acres[i] in the sub-catchments outside of the core project. For the purposes of estimation, GIS-based acre counts can be converted to approximate number of model impervious acres by multiplying by 0.6741.

Determining Areas Managed

Certain sub-basins from the SWMM geometry were identified as being managed based on the assumptions set forth in this chapter. These sub-basins were selected based upon the ease of connecting to downstream improvements and the ease of installing detain and release stormwater storage capacity. The "management rate" is the percentage of a sub-catchment's impervious area that is assumed to be managed through the assumptions in this chapter.

Determining Design Storm Volume for Estimating Demand for Detention

For each sub-catchment, Ethos Collaborative estimated the stormwater volume created by a design storm of 1.5" over 24 hours using the Small Storm Hydrology Method. This total volume was then multiplied by the management rate to provide an estimate of the total sub-catchment-wide stormwater storage volume that should be built in each sub-catchment.

i Based on 05 April 2019 SWMM presentation prepared by Mott MacDonald.

Determining Sub-catchment Performance

Sub-catchment performance was limited to estimating the annual volume of combined-sewer overflow removed. This was estimated by multiplying the number of estimated model impervious acres managed by a conversion ratio. For the purposes of estimation, impervious acres can be converted to millions of gallons of CSO removed annually by multiplying by 0.6556[i].

Determining Sub-catchment Costs

Costs in upper shed areas are based on unit costs, rules of thumb, and estimated infrastructure need to fully manage the selected sub-basins from the SWMM analysis for a design storm of 1.5" over 24 hours. Table 2.2 outlines each individual cost assumption type used in this analysis.

Cost Estimation Precision and Contingency

Unless otherwise noted, costs given in this memo are estimated ranges given best available data and reflect the depth of analysis to date. Cost estimates are within Class 5 estimation parameters as classified by the Association for the Advancement of Cost Engineering such that actual costs may be up to 50% lower than stated or up to 100% higher than stated. These ranges also accommodate the 30% contingency factor recommended by PWSA's Interim Stormwater Program Manager.[ii]

Given the large area studied in this memorandum, there may be estimates that fall outside of Class 5 estimation parameters. Further study as outlined in the Next Steps would substantially improve the surety of these estimates.

For the purpose of this planning exercise, these conservative unit costs are sufficient to provide orders of magnitude estimates for each of the 13 sub-catchment areas. These orders of magnitude cost estimates, while not being precise enough for implementation at this stage, are helpful in illustrating two important concepts:

1. **Networkability**: More expensive investments, when developed as part of a network, can enable more cost-effective investments in the future, raising overall sewershed cost-effectiveness. This improved cost-effectiveness is not possible if infrastructure is developed without an overall strategy to create a conveyance network. While individual projects may not meet cost-effectiveness thresholds, the overall cost-effectiveness of the network should be the driving consideration.
2. **Cost-sharing:** Because the Authority has site control of very few properties within its service area, PWSA's projects must always be coordinated with other agencies and stakeholders. By aligning its projects with the priorities and projects of others, PWSA could leverage the opportunity for integrated projects and allow for major cost savings. When the modest cost-sharing scenario in this memorandum is considered, it has a substantial impact on the cost-effectiveness of the overall network.

i Based on 05 April 2019 SWMM presentation by Mott MacDonald. This presentation identified that 241 model impervious acres were redirected for a modeling result of 158,000,000 gallons of CSO removed. Thus multiplying one impervious acre by 0.6556 gives us one million gallons of CSO removed. This is an even more conservative multiplier than 0.6860 which had been used previously.

ii Base cost with +30% contingency was suggested at a working meeting on 08 March 2019 at PWSA.

Watershed Expansion Methodology (continued)

Assessing Cost-Effectiveness

This memorandum considers two metrics of cost-effectiveness:

1. Cost per Impervious Acre Managed
2. Cost per Annual CSO gallon Removed

The Cost per Impervious Acre Managed metric is widely used in other regions and thus allows for easy comparison between projects using different technologies and in different contexts. The challenge with the impervious acre managed metric is that the ratio of an impervious acre removed relative to CSO gallons removed differs from shed-to-shed and city-to-city. Thus comparing this metric from one shed to another does not truly offer an apples-to-apples comparison of cost-effectiveness relative to the actual goal of removing a volume of combined-sewer overflow.

Based on guidance from the PWSA program management, projects should be considered especially cost-effective when they achieve a ratio of $250,000/impervious acre managed. PWSA's Shadyside/A-22 Sewershed Flooding Solutions & Green Infrastructure Assessment Project suggests a cost range of $324,000 - $432,000 on average per impervious acre managed.[i] ALCOSAN's August 2015 Starting at the Source report offers an average capital cost per impervious acre of $378,000.[ii]

The Cost per Annual CSO gallon Removed metric is the preferred metric of the Watershed Expansion Team as it allows direct comparison between projects in different sheds that have different hydraulic conditions. In the M-29 sewershed expansion scenario in this memorandum, each impervious acre managed leads to a CSO volume removal of 655,600 gallons.[iii]

Based on informal guidance from PWSA's program management in early 2019, this memorandum's goal for cost-effectiveness of $0.75/annual CSO gallon removed.

In M-29, a managed impervious acre leads to the removal of 655,600 gallons of CSO annually. A single impervious acre managed in M-29 at a cost of $250,000 would thus be $0.38/annual CSO gallon removed. In M-29, a single impervious acre managed with a cost-effectiveness of $0.75/annual CSO gallon removed would cost $491,700.

As PWSA develops its stormwater portfolio it will continuously gain insights into the types of projects that are most cost-effective and a more rigorous understanding of what projects should cost. As it develops this portfolio, the thresholds for what the Authority considers to be affordable are likely to become more precise. Additionally, the most cost-effective projects will be prioritized for implementation. Once these "easy win" projects are completed, PWSA will need to tackle more challenging projects to continue to reduce CSO volumes. Thresholds will likely rise after the most cost-effective projects are implemented.

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i PWSA 2016 Green First Plan, 7-2.
ii PWSA 2016 Green First Plan, 7-2.
iii Based on 05 April 2019 SWMM presentation by Mott MacDonald. This presentation identified that 241 model impervious acres were redirected for a modeling result of 158,000,000 gallons of CSO removed. Thus multiplying one impervious acre by 0.6556 gives us one million gallons of CSO removed. This is an even more conservative multiplier than 0.6860 which had been used previously.

Alignment with Other Projects

A network of distributed green infrastructure across neighborhoods must be a coordinated effort that is aligned with all possible and anticipated infrastructure and community needs. PWSA should engage early and often with all possible coordinating partners including:

- Electric utilities
- Gas utilities
- Telecommunications infrastructure owners
- City Department of Mobility and Infrastructure
- Pennsylvania Department of Transportation
- Community groups
- Adjacent private property owners

By aligning with planned improvements by coordinating partners, PWSA can offer design standards to which partners should build to. PWSA can also enter into an agreement for a "dig-once" project that achieves multiple infrastructure goals with cost-savings for all partners and minimized disturbance. Additionally, a "dig-once" strategy minimizes the opportunity for damage to PWSA's green infrastructure that would be caused by future construction by other agencies.

Understanding when coordinating partners are planning to make their improvements is important for PWSA to create its own Infrastructure Development Plan. Such a plan would prioritize projects with a favorable cost-share for PWSA.

The Green First Goals

The Green First Plan (2016) is PWSA's framework for evaluating priority green infrastructure projects.

There are five goals that each project should address:

COMPLIANT
Does the project achieve regulatory compliance with local, state, and federal requirements (eg. CSO, MS4, DEP Consent Order etc.)?

AFFORDABLE
Does the project meet desired performance metrics for cost? This memorandum's goal for affordability is $0.75 per annual gallon of CSO removed.

ENGINEERED
Does the project meet rigorous design and feasibility standards?

BENEFICIAL
Does the project offer benefit to the community and maximize the triple bottom line?

REPLICABLE
Does the project utilize practices and designs that can be used throughout the PWSA service area?

Future Costs & Benefits

Future planning should also consider additional sources of cost:

- Annual maintenance costs
- General inflation
- Construction inflation for future phases
- Future cost of capital
- Future infrastructure renewal

Future planning should also consider additional project benefits:

- Management of runoff from pervious surfaces (only imp. considered now)
- Flood mitigation
- MS4 compliance
- Triple bottom line benefits (home values, public health, workforce development, etc.)

Watershed Expansion Methodology (continued)

Table 2.2 Cost Assumption Variables Considered

Improvement type and assumption basis	Units	Unit Cost
RIGHT-OF-WAY CONVEYANCE IMPROVEMENTS utilizing a standard design detail from a select of PWSA and City approved designs. At the highest-capacity end of the spectrum this would encompass curb-side flow-through bioswales with subsurface detention (approximately $450/ft). For medium-capacity conveyance and detention this would encompass a revised curb profile and networked tree pits ($150/ft). At the low-capacity end of the spectrum, this would encompass a revised curb profile for conveyance ($50/ft). In some locations, additional conveyance capacity can be very cheaply added to the roadway simply by grinding the pavement adjacent to the curb. $200/ft is a simplified estimate to encompass this full range of possibilities and is appropriate for the level of study to date.	Per linear foot of roadway	$200/ft
INTERSECTION WITH GREEN BUMP-OUTS and subsurface inlet bypass pipes. Estimated based on sum of materials and mobilization costs.	Per each	$325,000/ each
NATURALIZED WATERWAY, CULVERT, OR DITCH in challenging to access areas such as steep slopes. Based on stream design literature.	Per linear foot	$600/ft
PROPERTY ACQUISITION MULTIPLIER. This multiplier includes inflated market value and administrative fees. Market values based on Allegheny County fair market value (FMV).	Multiplier	2 X County FMV
SUBSURFACE DETENTION such as R-Tanks including excavation, shoring, and supporting infrastructure. Based on the Watershed Expansion Team's professional experience, the raw storage cost is approximately $12/cf including excavation and shoring. Multiplying this figure by 1.5 accounts for supporting infrastructure and site-specific complications.	Per cubic foot of storage capacity	$18/cf
PLAYING FIELD RESTORATION on top of subsurface storage. Based on available literature for artificial turf fields.	Per square foot	$15/sf
HORIZONTAL DIRECTIONALLY DRILLED PIPE. Based on Vilfrant 2010, page 68, based on average for 23 wastewater projects. Inclusive of mobilization, urban area easements, etc. Vilfrant's average was modified from $1358.40/ft/48"-pipe to $1920.00/ft/48"-pipe based on guidance from PWSA's Interim Stormwater Program Manager and to account for inflation. This cost is also stated as $40.00/ft/inch-pipe-diameter.	Per linear foot assuming 48" pipe	$1920/ft
DOWNSPOUT DISCONNECTION. Based on evolveEA and PWSA residential experience. Assumes that each household would be included in a neighborhood-scale disconnection program and not one-off. This is a conservative estimate with substantial contingency to account for unique conditions that may be discovered. For reference, PWSA performed disconnections at Red Oak & Hayson for approximately $400/home.	Per household	$1000/ home

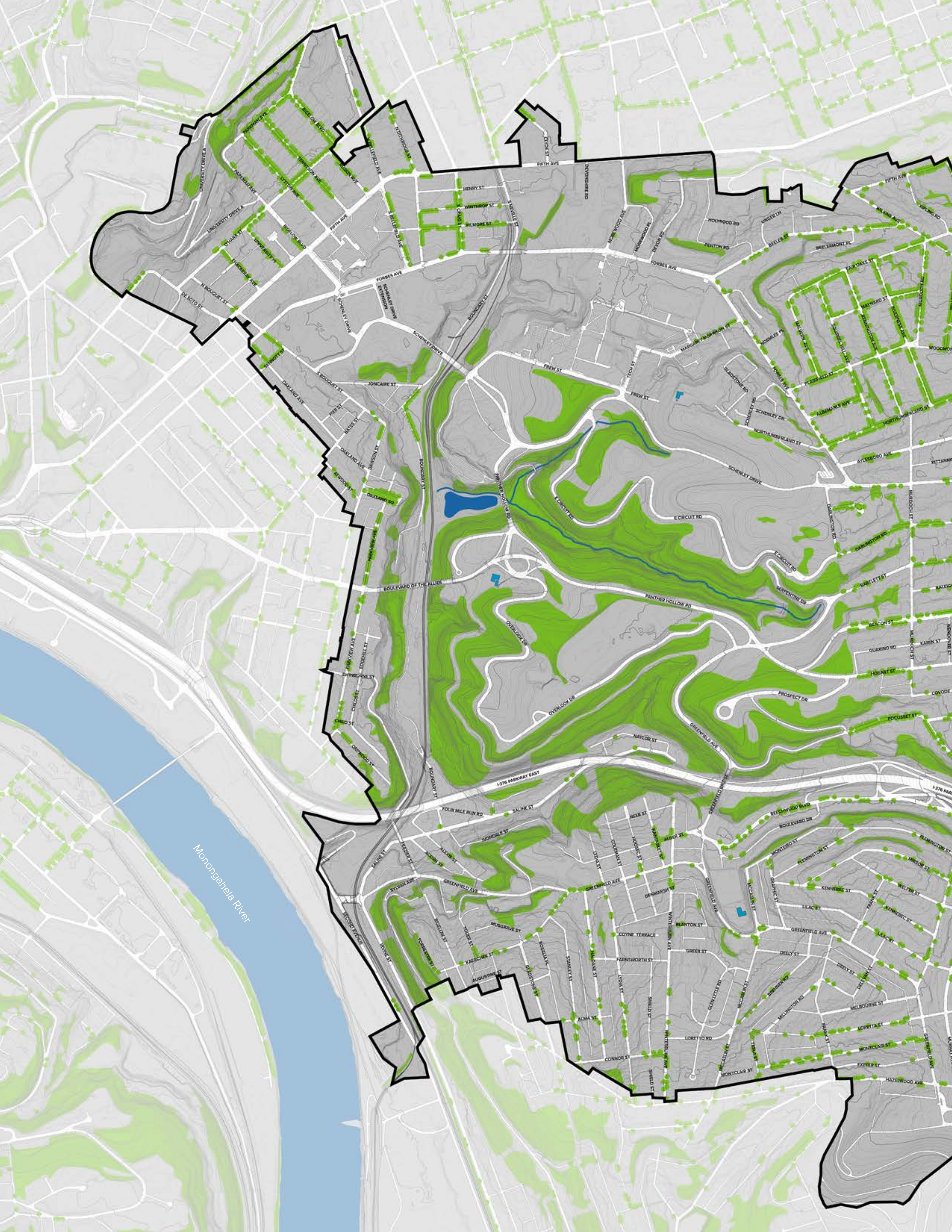
Developing a Shed-wide Cost-Sharing Scenario

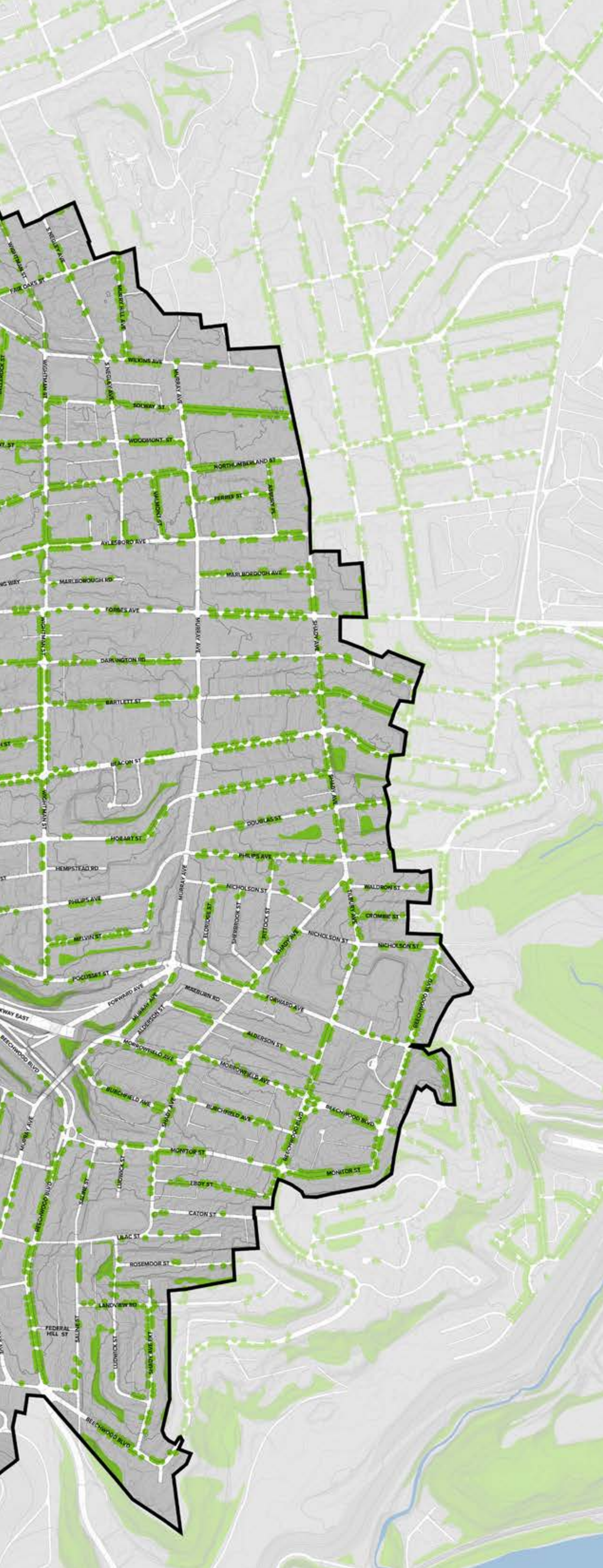
For the purposes of discussion, a cost-sharing scenario was evaluated that illustrates a possible split between PWSA and coordinating partners. It is assumed that costs would be shared when projects are aligned and coordinated and that the savings realized due to a "dig-once" policy would be shared among partners. The cost-sharing scenario assumptions are outlined in Table 2.3. For planning and discussion purposes, an average share-of-cost was estimated across the board for each improvement type.

For roadway restoration cost in particular, the Watershed Expansion Team suggests that the City and PWSA agree upon cost-sharing in terms of remaining service life of the roadway. The remaining service life of the roadway could be tied directly to the Pavement Condition Index which equates a well-defined numerical condition rating to years of service life remaining, for a variety of road classifications. In such an arrangement, PWSA would not be fully responsible for paying for roadway restoration for pavement that is already in poor condition. For some particularly poor quality roadways, PWSA would theoretically not pay any restoration cost at all.

Table 2.3 Cost-Sharing Scenario

Improvement type	Cost-share Partners	PWSA's Share of Cost
CORE PROJECT COST-SHARING While the specifics of the core project cost and cost sharing opportunities are being developed separate from this memorandum, this cost-sharing scenario includes the assumption that PWSA shall be responsible for 80% of the project cost.	DOMI, Parks, PENNDOT, Philanthropy	80%
RIGHT-OF-WAY CONVEYANCE IMPROVEMENTS Based on likely roadway conditions, PWSA would be responsible for 70% of the cost of implementing GI in right-of-ways in this scenario.	DOMI, DPW, PENNDOT	70%
INTERSECTION WITH GREEN BUMP-OUTS Based on likely roadway conditions and existing compliance with ADA at City intersections, PWSA would be responsible for 60% of the cost of implementing GI at an intersection in this scenario.	DOMI, DPW, PENNDOT	60%
NATURALIZED WATERWAY, CULVERT, OR DITCH Most of these types of conveyance connections occur on steep slopes which are places with already unstable slopes or where there is ecological degradation due to invasive species or illegal dumping. It is assumed that PWSA would be responsible for 90% of the cost of implementing GI in this scenario.	DOMI, DPW, Parks, Greenways, DCNR	90%
PLAYING FIELD RESTORATION Based on the condition of playing fields and their remaining service life, PWSA would be responsible for 50% of the cost of restoring a playing field on top of a sub-surface detention facility in this scenario.	DPW, Parks	50%


Monongahela River
FIFTH AVE
FORBES AVE
SCHENLEY DRIVE
FREW ST
BOULEVARD OF THE ALLIES
PANTHER HOLLOW RD
OVERLOOK DR
E CIRCUIT RD
PROSPECT DR
GREENFIELD AVE
I-376 PARKWAY EAST
NAYLOR ST
HAZELWOOD AVE



3

Sub-catchment Areas

Map of wooded areas and street trees.

1 | PROJECT CATCHMENT AREA

The Four Mile Run Stormwater Improvement project has these major components:

- Improvements to Phipps and Panther Hollow Runs
- Reconstruction of Panther Hollow Lake
- A conveyance pipe from Panther Hollow Lake to the Junction Hollow Valley
- New conveyance channel through the Junction Hollow valley
- New conveyance channel and culverts through the Run neighborhood connecting the Junction Hollow Valley and Naylor Street to Hazelwood Green
- New conveyance channel and culverts through Hazelwood Green with an outlet to the Monongahela River

Performance

Based on Mott MacDonald's system-wide SWMM analysis from 05 April 2019:.

Impervious Acres Managed	59
Annual CSO Gallons Removed	41 MG

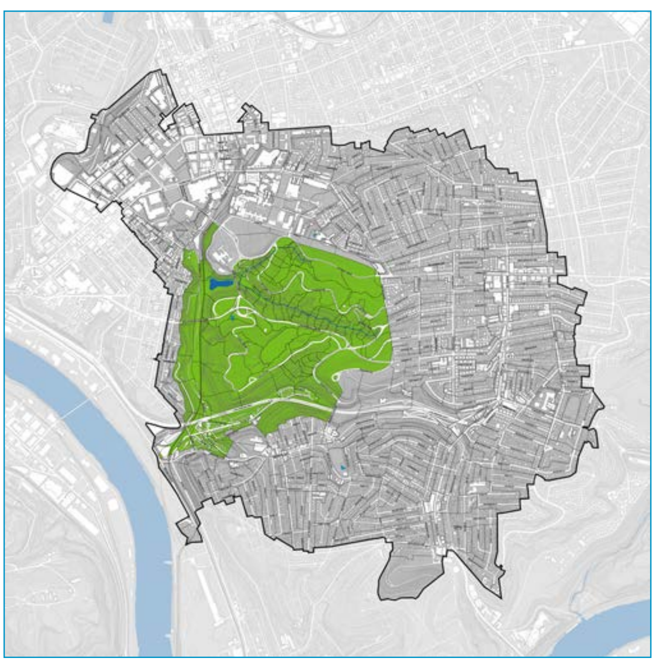
Cost Estimate

Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%.

Estimated Cost	$8,100,000 - $16,200,000
$/Imp. Acre Managed	$137k - $275k
$/Gal	$0.20 - $0.40

Cost-Sharing Scenario

These costs apply only to the stormwater components. Other non-stormwater aspects will require cost-sharing but this was not included in this planning exercise.



Locator Map

Sewer Network Map

Area 457.4 acres

Impervious Area 67.3 acres

Percentage Impervious 15 %

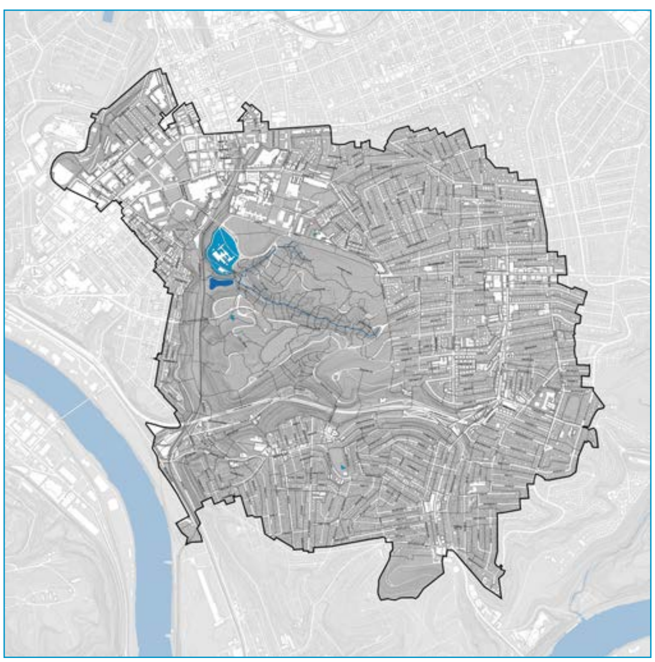
Performance evaluated in Mott MacDonald SWMM Model.

2 | PHIPPS CONSERVATORY

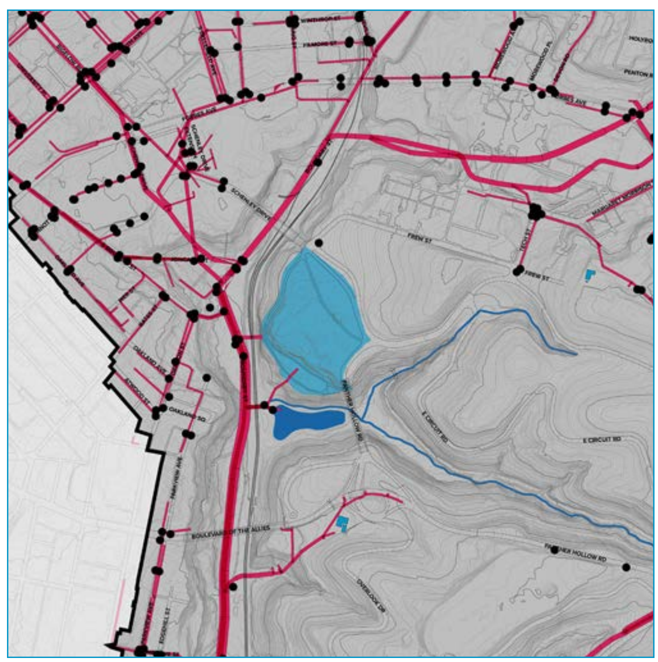
Phipps Conservatory is a unique site in this sewershed as it is hydrologically isolated from surrounding runoff sources and the Conservatory makes a deliberate effort to control stormwater on-site. As a non-profit dedicated to environmental causes, Phipps Conservatory constructed thoughtful and cutting-edge stormwater infrastructure on its site well in advance of PWSA's planning efforts.

As Phipps Conservatory is isolated within the shed, the watershed expansion team isolated it from this analysis. It is assumed that no further improvements are necessary at this site and thus no additional costs or performance are anticipated beyond current conditions.

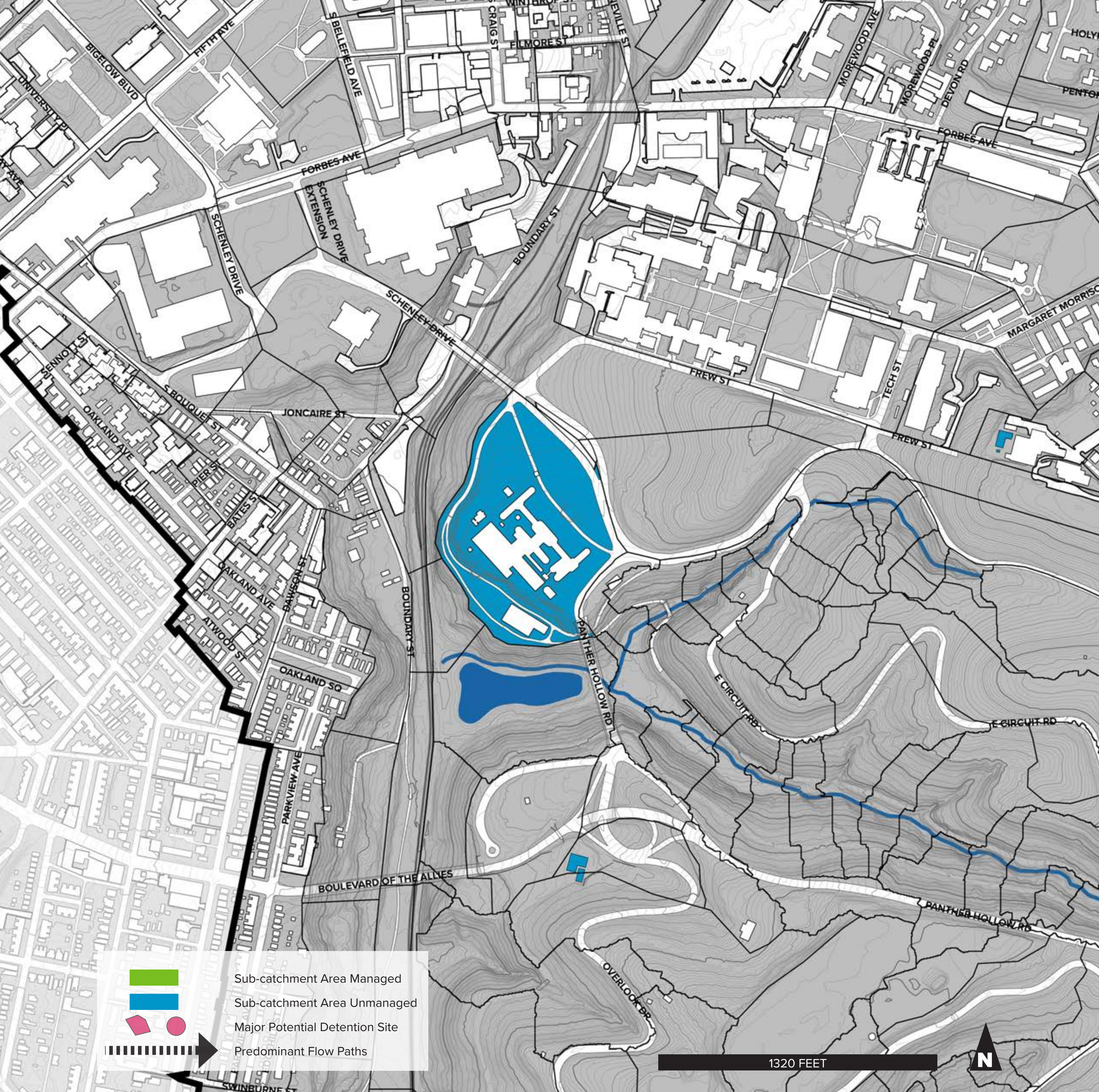
No planned improvements in this sub-catchment area, thus performance and cost were not evaluated.



Locator Map



Sewer Network Map



Area	**16 acres**
Impervious Area	**5.3 acres**
Percentage Impervious	**33 %**

To the knowledge of this team, it is assumed that Phipps Conservatory already manages their stormwater on-site beyond regulatory requirements. Thus this project would be unimpacted by the stormwater on this site.

3 | SOUTH OAKLAND

The South Oakland catchment is 25 acres of urban park land and residential neighborhood. The land surface flows towards Boundary Street at the southern end of the Junction Hollow Trail. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system through the catchment.

Based on field investigations, there is opportunity to convey stormwater from the South Oakland neighborhood from Swinburne Street, down the hillside to the proposed stream channel. This type of conveyance may require steep slope pipes to convey runoff from the Swinburne Street edge-of-pavement to the soccer field approximately 100 feet below. This type of pipe slope conveyance is frequently used on highway projects, in particular within areas of steep cut slope construction. Alternately, Swinburne Street (North) runoff could be conveyed to one of several tributary headwaters that exist along that slope, perhaps utilizing Regenerative Stormwater Conveyance design practices, similar to those pioneered in Maryland and West Virginia.

Performance

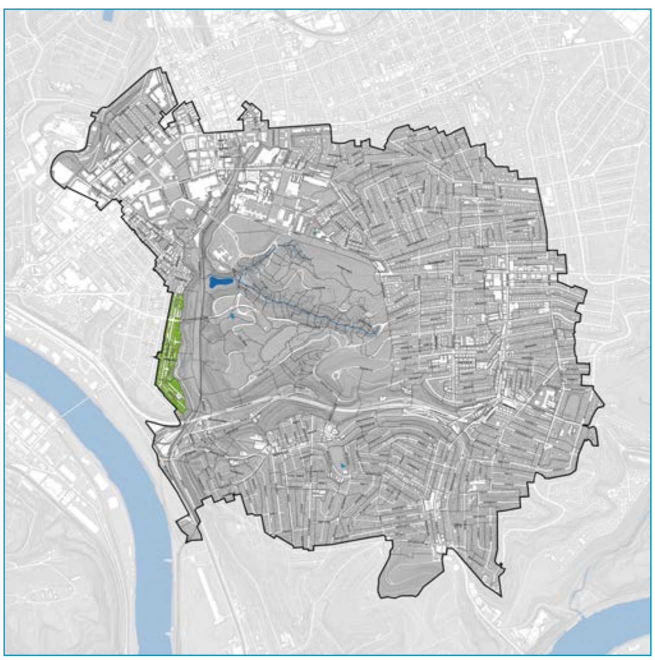
Impervious acres managed	7.3
Annual CSO Gallons Removed	4.8 MG

Cost Estimate

4 intersections @ $325,000	$1,300,000
1,320 ft conveyance @ $600	$792,000
1,320 ft ROW improvements @ $200	$264,000
34,258 cu ft stormwater storage @ $18	$616,650
40 downspout disconnections	$40,000
Total Cost Estimate	$3,012,650
Class 5 Cost Range	$1,506,325 - $6,025,299
$/Imp. Acre Managed	$206k - $825k
$/Gal	$0.31 - $1.25

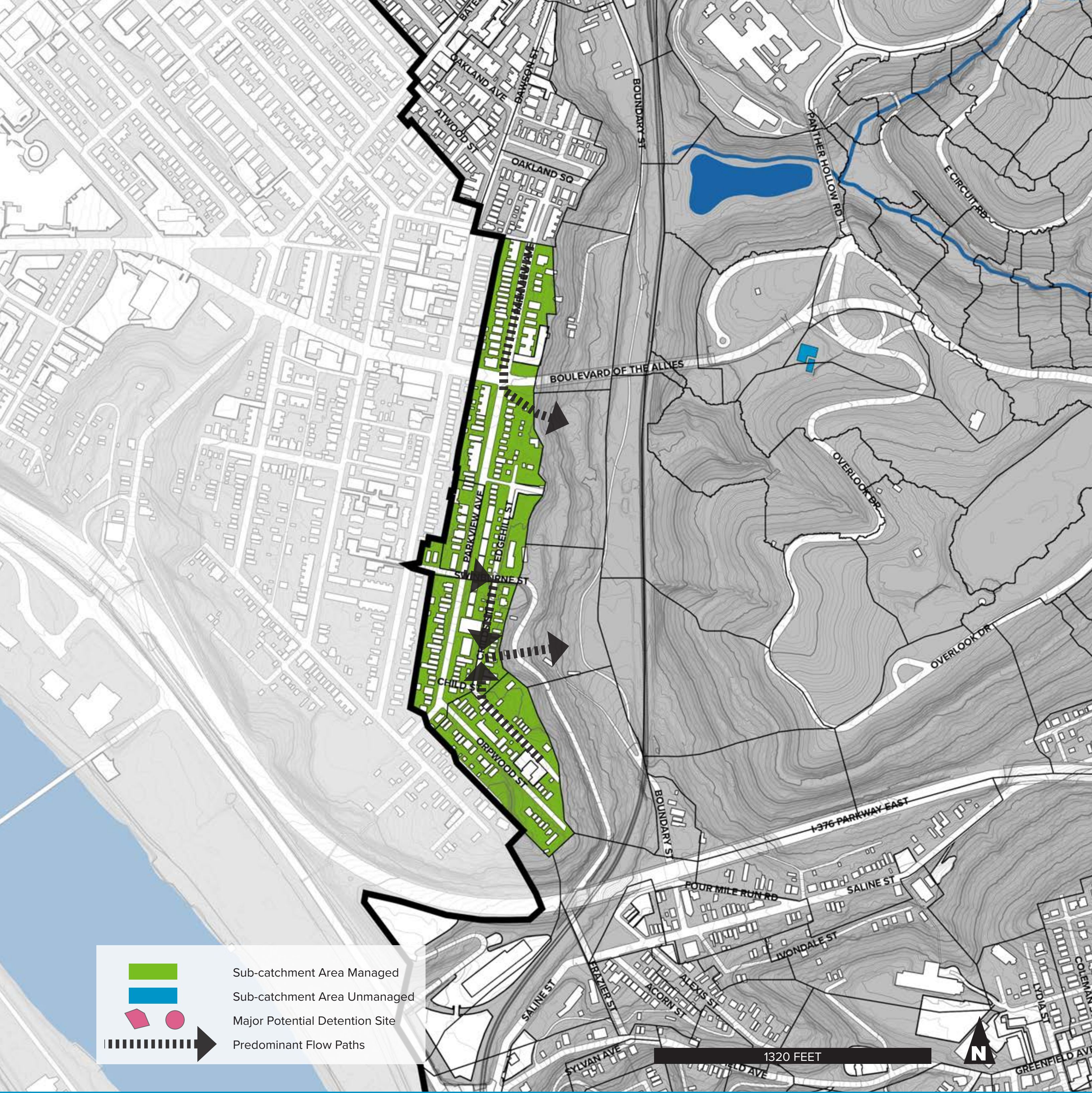
Cost-Sharing Scenario

Class 5 Cost Range	$1,167,125 - $4,668,499
$/Imp. Acre man. w/ cost-share	$159k - $636k
$/Gal w/cost-sharing	$0.24 - $0.97



Locator Map

Sewer Network Map



Area	**25.2 acres**
Impervious area	**7.3 acres**
Percentage Impervious	**43%**
Impervious area managed	**7.3 acres**
Management Ratio	**100%**
1.5", 24hr impervious runoff total	**256,270 gallons**
1.5", 24 hr impervious runoff managed	**256,270 gallons**

4 | OAKLAND

The Oakland catchment is a 301-acre, highly urbanized, institutional neighborhood bisected by Bellefield and Forbes Avenue. The land surface flows towards Schenley Plaza/Boundary Street at the Panther Hollow Road underpass. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system through the downstream catchment (Swinburne Street North).

The vast number of civic parks, green spaces, and parking facilities within Oakland, create numerous opportunities for stormwater storage within this sub-catchment area. These include Schenley Plaza, Forbes Field, the Cathedral of Learning, and the Petersen Event Center. Although it would be a long-term commitment to construct these various storage nodes and provide the necessary urban stormwater conveyance network, the institutions may prove to be cooperative and collaborative with PWSA. It is important that PWSA begin conversations to include advantageous network-scale solutions into their institutional master plans.

Performance

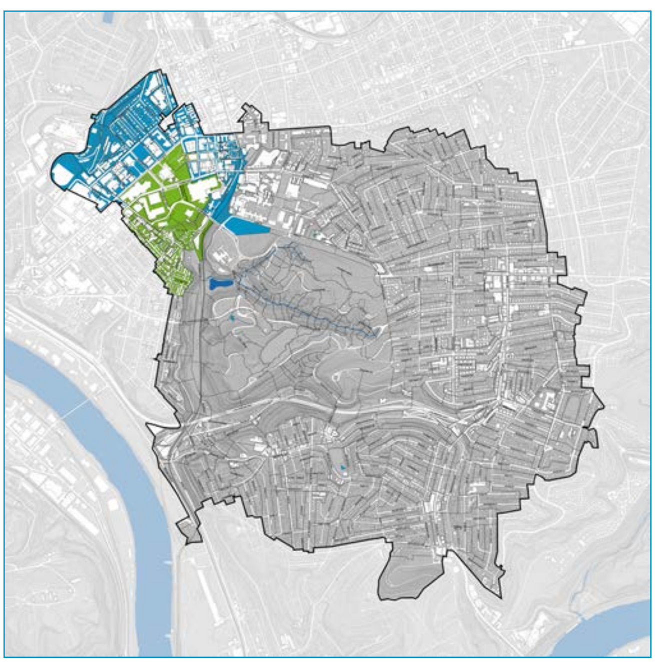
Impervious acres managed	40.5
Annual CSO Gallons Removed	26.6 MG

Cost Estimate

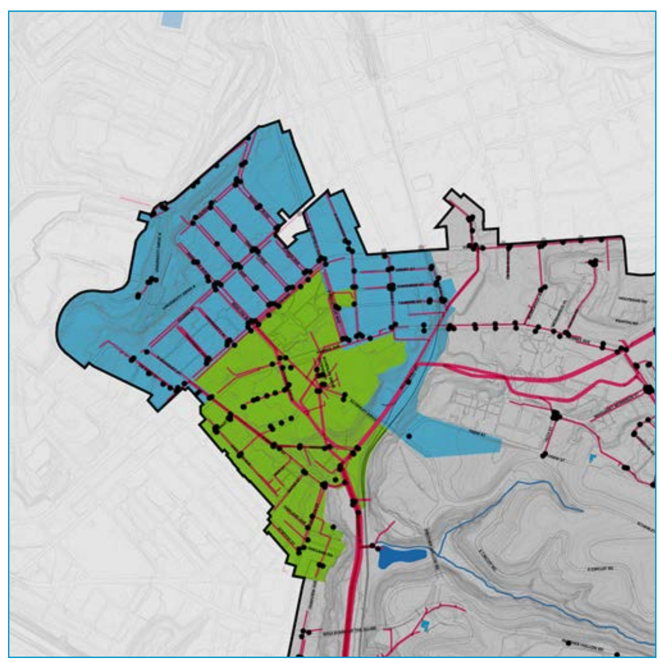
20 intersections @ $325,000	$6,500,000
1,320 ft conveyance @ $600	$792,000
5280 ft ROW improvements @ $200	$1,056,000
Property Acquisition	$1,563,200
178,404 cu ft stormwater storage @ $18	$3,211,277
40 downspout disconnections	$40,000
Total Cost Estimate	$13,162,477
Class 5 Cost Range	$6,581,239 - $26,324,954
$/Imp. Acre Managed	$162k - $650k
$/Gal	$0.25 - $0.99

Cost-Sharing Scenario

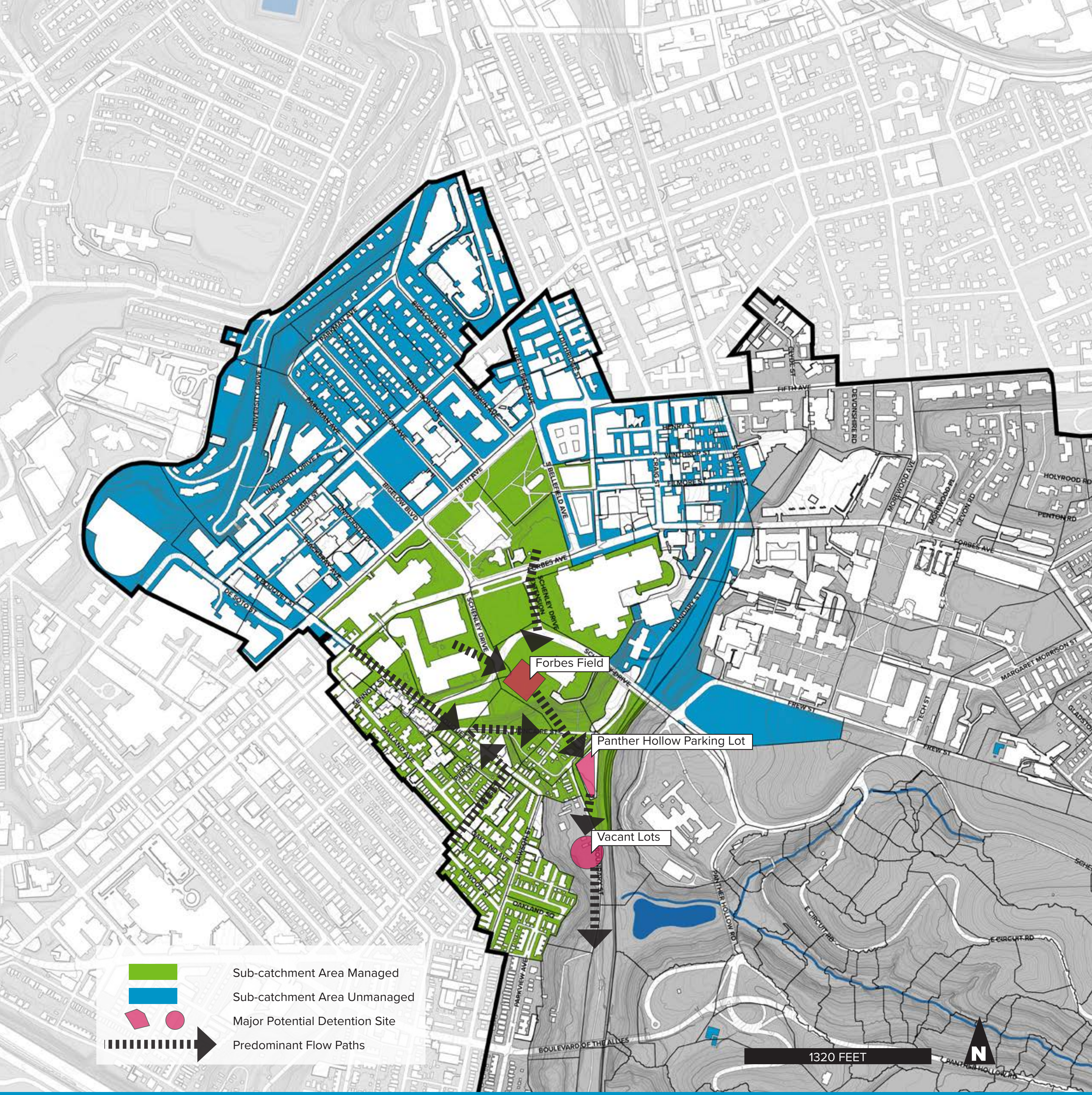
Class 5 Cost Range	$5,083,239 - $20,332,954
$/Imp. Acre man. w/ cost-share	$125k - $502k
$/Gal w/cost-sharing	$0.19 - $0.77



Locator Map



Sewer Network Map



Area	**301.1 acres**
Impervious area	**106.7 acres**
Percentage Impervious	**53%**
Impervious area managed	**40.5 acres**
Management Ratio	**38%**
1.5”, 24hr impervious runoff total	**3,513,940 gallons**
1.5”, 24 hr impervious runoff managed	**1,334,557 gallons**

5 | CARNEGIE MELLON

The Carnegie Mellon University catchment is a 171-acre, highly urbanized, university setting bisected by Forbes Avenue and Boundary Street. The land surface flows towards Boundary Street at the intersection with Joncaire Street. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system.

CMU presents a unique challenge and opportunity with respect to stormwater conveyance to the proposed stream. The campus is situated directly over a significant historical stream bed that was long ago culverted and built upon. This historical stream bed runs generally east to west, and traverses directly underneath the soccer along Forbes Avenue, under Margaret Morrison Carnegie Hall, beneath the tennis courts and Quad space, and through the Hamerschlag Drive corridor. A horizontal directionally drilled pipe could allow upstream areas to connect to Junction Hollow under CMU's campus.

Newer buildings on campus have separate storm lines that connect back to the combined sewer. PWSA and CMU should explore opportunities for segregating storm and sewer from redundant combined lines.

Performance

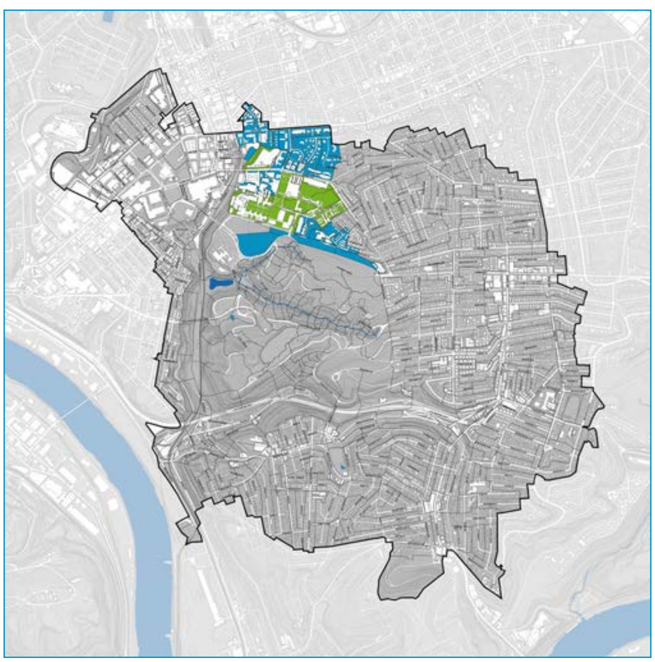
Impervious acres managed	22.0
Annual CSO Gallons Removed	14.4 MG

Cost Estimate

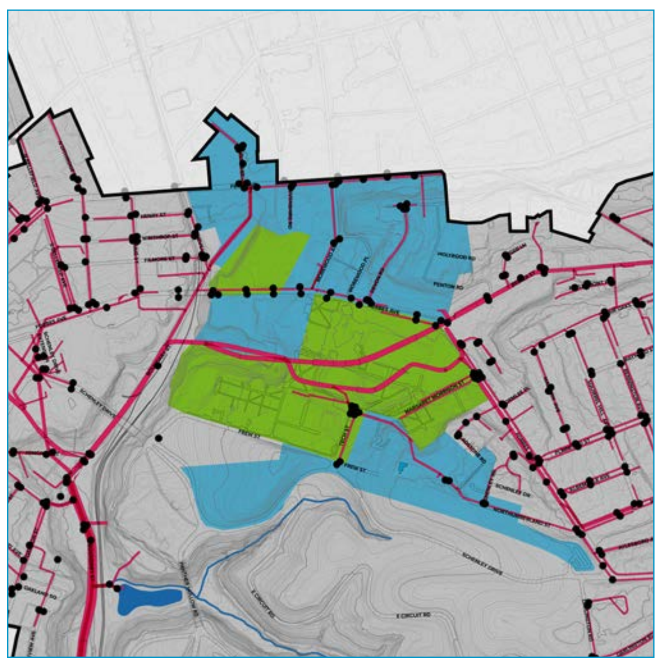
6 intersections @ $325,000	$1,950,000
1320 ft ROW improvements @ $200	$264,000
104,255 cu ft stormwater storage @ $18	$1,876,598
2,640 ft of 48" HDD pipe	$5,068,800
20 downspout disconnections	$20,000
Total Cost Estimate	$9,179,398
Class 5 Cost Range	$4,589,699 - $18,358,796
$/Imp. Acre Managed	$209k - $834k
$/Gal	$0.25 - $1.27

Cost-Sharing Scenario

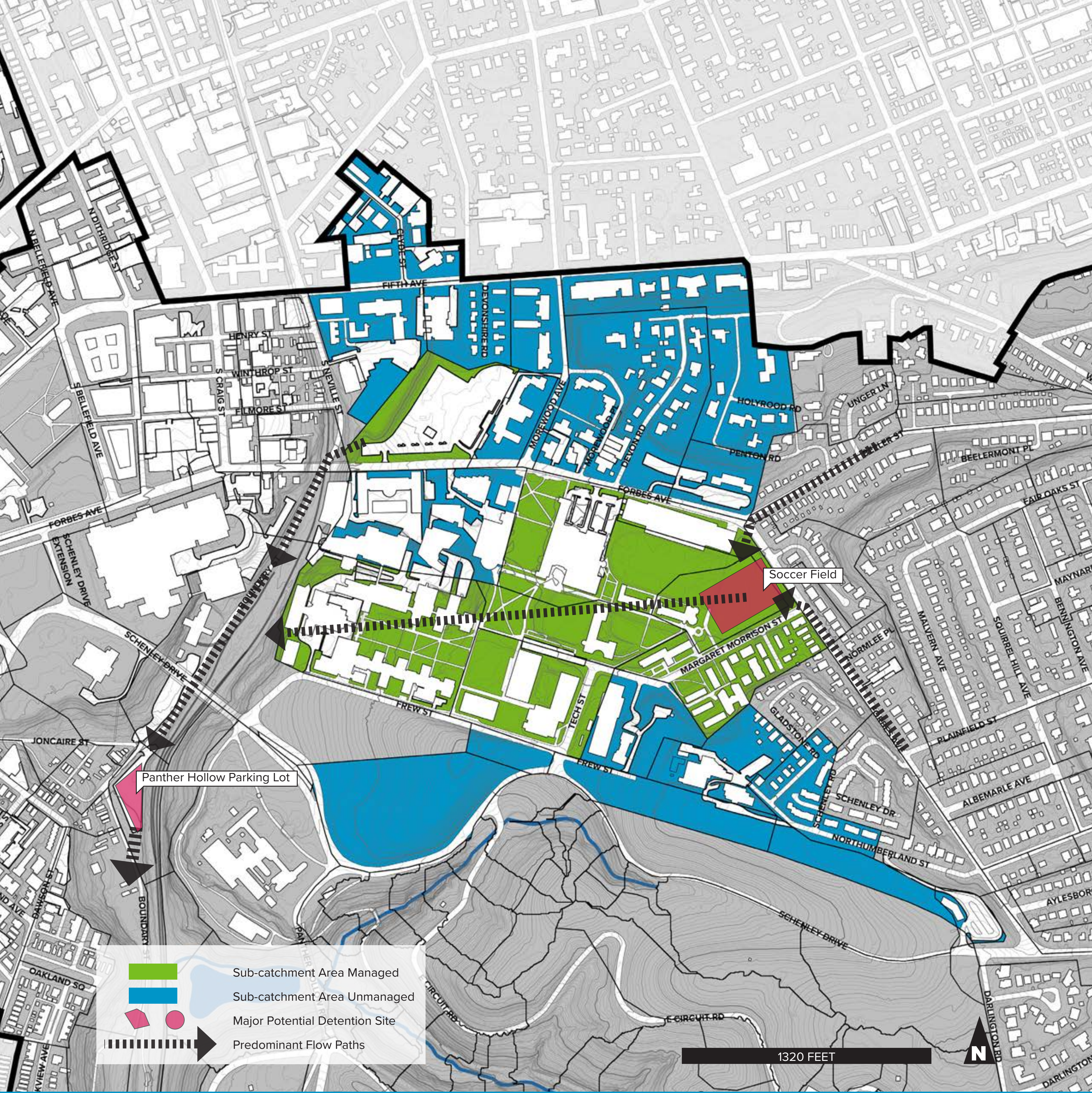
Class 5 Cost Range	$4,160,099 - $16,640,396
$/Imp. Acre man. w/ cost-share	$189k - $756k
$/Gal w/cost-sharing	$0.29 - $1.15



Locator Map



Sewer Network Map



Area	**171.0 acres**
Impervious area	**50.0 acres**
Percentage Impervious	**43%**
Impervious area managed	**22.0 acres**
Management Ratio	**44%**
1.5”, 24hr impervious runoff total	**1,770,284 gallons**
1.5”, 24 hr impervious runoff managed	**779,885 gallons**

6 | FORBES AVENUE

The Forbes Avenue catchment is a 102-acre, moderately urbanized, residential neighborhood bisected by Forbes Avenue. The land surface flows towards Forbes Avenue at the intersection with Beeler Street. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system through the downstream catchment (Carnegie Mellon).

Like the Squirrel Hill North catchment, this sub-catchment area presently drains to the existing combined sewer system that runs directly beneath Carnegie Mellon campus. Unlike Squirrel Hill North however, the majority of the roads in this catchment are under local City jurisdiction, with the exception of Forbes Avenue, which is a PennDOT road. The streets in this sub-catchment area are also generally wider and aligned along contour, rather than on grade. This makes the surrounding neighborhood ideal for urban green stormwater infrastructure retrofits within the right-of-way, including stormwater tree pits, porous pavement parking strips, enhanced curb and gutter treatments, and linear green streets and green intersections.

Performance

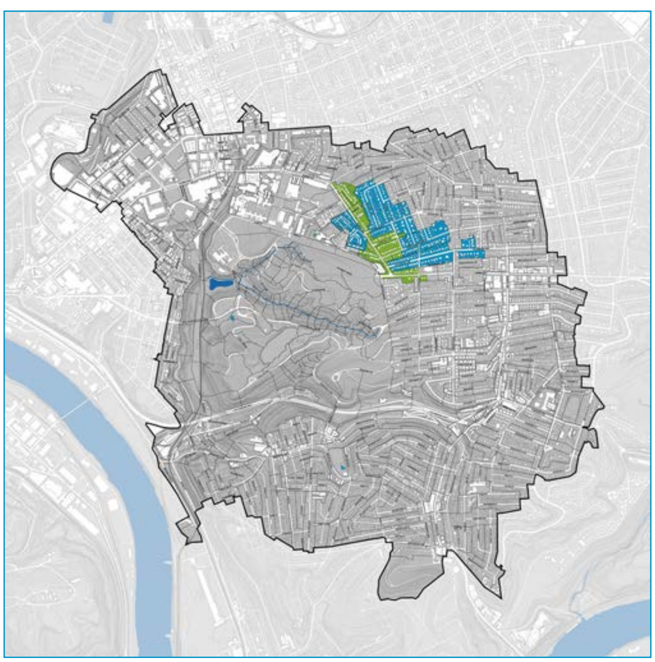
Impervious acres managed	8.1
Annual CSO Gallons Removed	5.3 MG

Cost Estimate

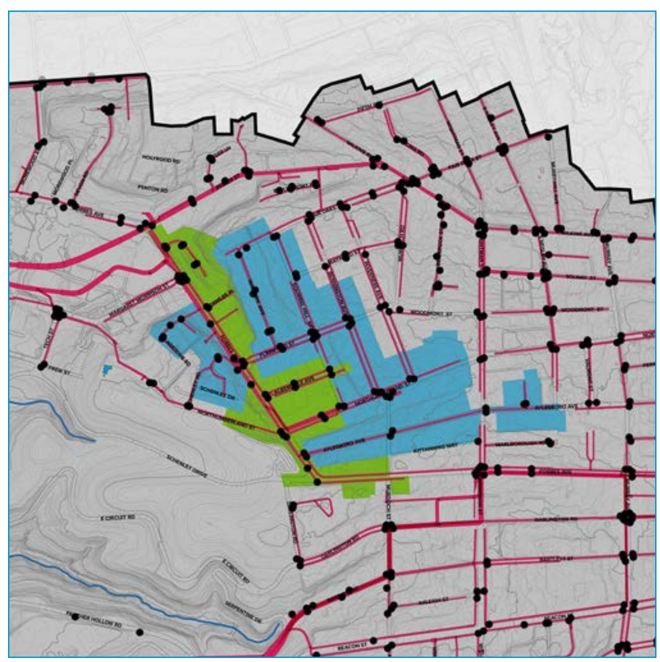
8 intersections @ $325,000	$2,600,000
2,640 ft ROW improvements @ $200	$528,000
37,408 cu ft stormwater storage @ $18	$673,347
60 downspout disconnections	$60,000
Total Cost Estimate	$3,861,347
Class 5 Cost Range	$1,930,673 - $7,722,694
$/Imp. Acre Managed	$238k - $953k
$/Gal	$0.36 - $1.45

Cost-Sharing Scenario

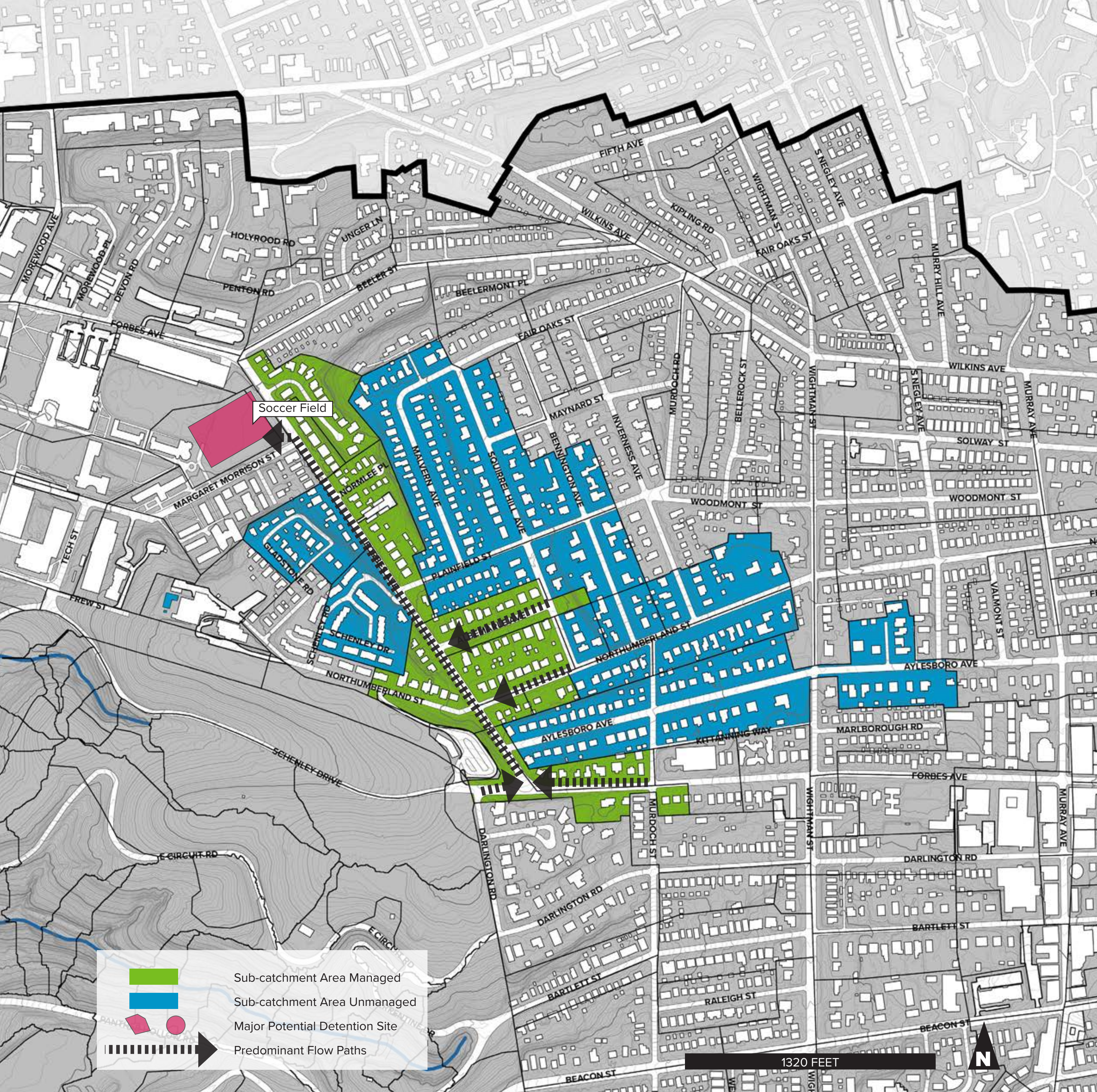
Class 5 Cost Range	$1,331,473 - $5,325,894
$/Imp. Acre man. w/ cost-share	$164k - $657k
$/Gal w/cost-sharing	$0.25 - $1.00



Locator Map



Sewer Network Map



Area	**101.5 acres**
Impervious area	**23.7 acres**
Percentage Impervious	**35%**
Impervious area managed	**8.1 acres**
Management Ratio	**34%**
1.5", 24hr impervious runoff total	**819,153 gallons**
1.5", 24 hr impervious runoff managed	**279,833 gallons**

7 | SQUIRREL HILL NORTH

Stormwater conveyance through this sub-catchment area is routed primarily along Beeler Street, which is located along the bottom of a shallow, narrow valley that drains this portion of Squirrel Hill from above Wilkins Avenue to the just upstream of the CMU soccer fields at Forbes Avenue. It is believed that Beeler Street was constructed over the historical stream in this area, and so it is anticipated that this street sees substantial flow during heavy rain events. Both Beeler Street and Wilkins Avenue are PennDOT routes, and would require coordination with the state to achieve any substantial storage or conveyance in the right-of-way. Substantial storage is planned for a portion of the sub-catchment area, at Wightman Park, near the intersection of Wightman Street and Wilkins Avenue.

Connection of the Squirrel Hill North/Beeler Street sub-catchment area is challenging because the sewer system is directly under the Carnegie Mellon University campus. The design team is exploring whether the historical stream flow is conveyed in a dedicated separated system or if there are ways to disconnect existing sanitary sewer flow from the existing pipes where redundancy exists.

Performance

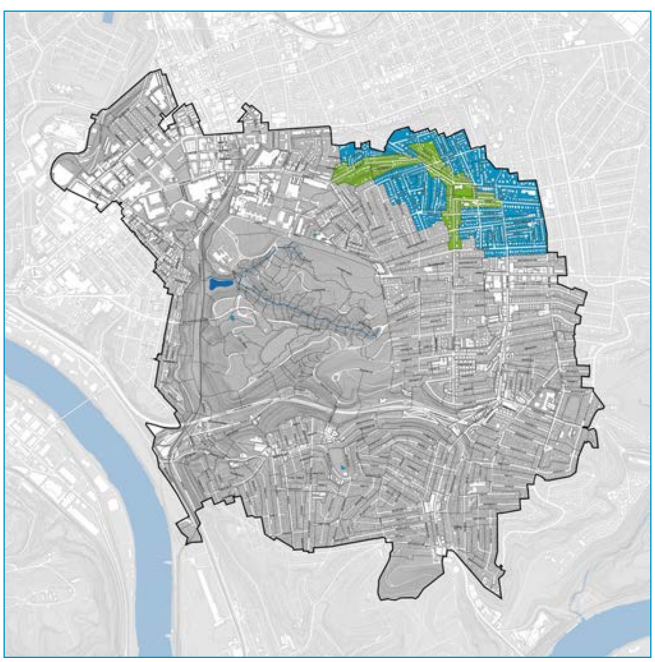
Impervious acres managed	14.1
Annual CSO Gallons Removed	9.3 MG

Cost Estimate

12 intersections @ $325,000	$3,900,000
5,280 ft ROW improvements @ $200	$1,056,000
60,497 cu ft stormwater storage @ $18	$1,088,955
100 downspout disconnections	$100,000
Total Cost Estimate	$6,144,955
Class 5 Cost Range	$3,072,477 - $12,289,909
$/Imp. Acre Managed	$217k - $867k
$/Gal	$0.33 - $1.33

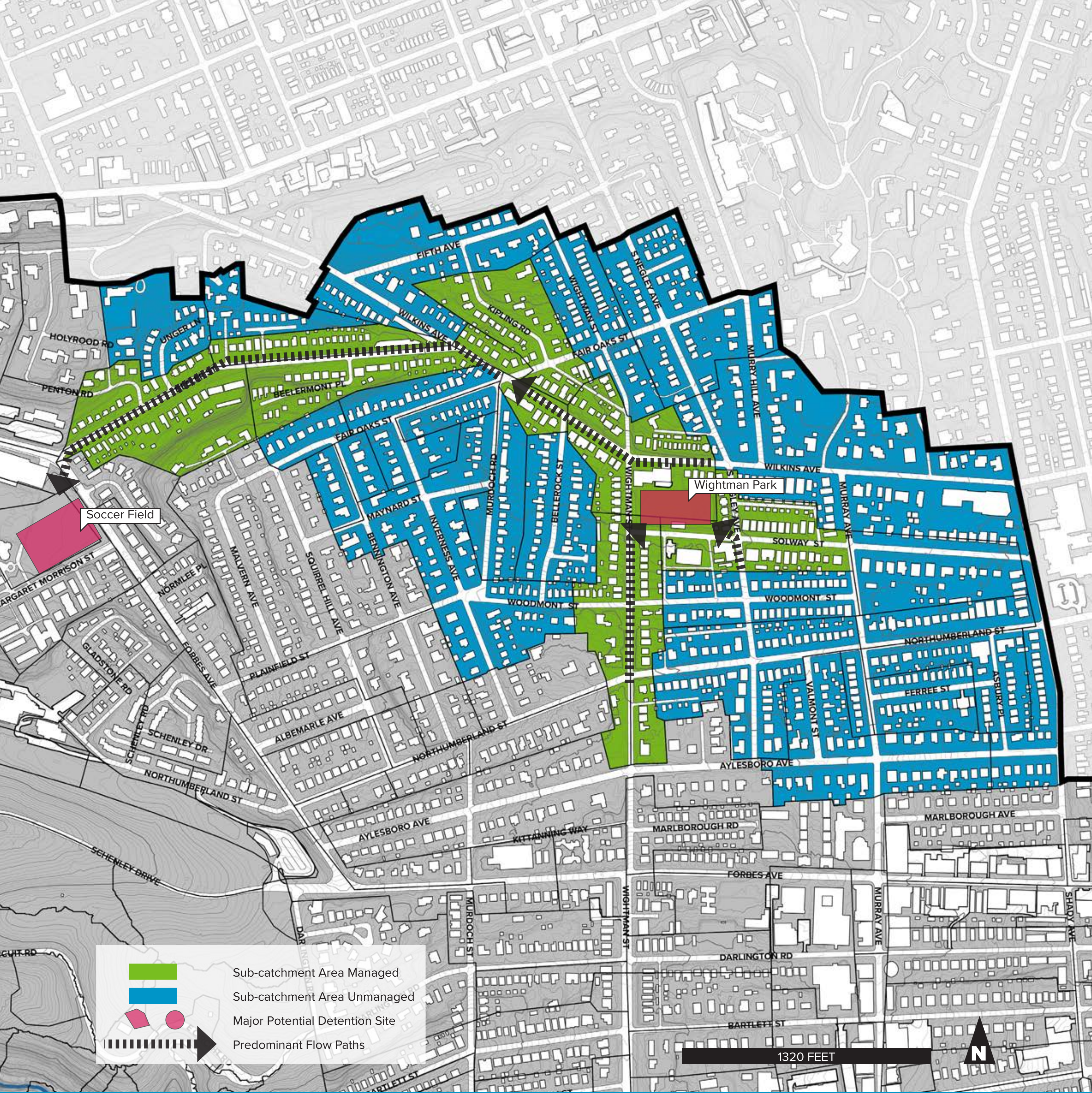
Cost-Sharing Scenario

Class 5 Cost Range	$2,134,077 - $8,536,309
$/Imp. Acre man. w/ cost-share	$151k - $603k
$/Gal w/cost-sharing	$0.23 - $0.92



Locator Map

Sewer Network Map



Area	**215.9 acres**

Area	**215.9 acres**
Impervious area	**52.6 acres**
Percentage Impervious	**36%**
Impervious area managed	**14.1 acres**
Management Ratio	**27%**
1.5”, 24hr impervious runoff total	**1,681,533 gallons**
1.5”, 24 hr impervious runoff managed	**452,553 gallons**

8 | BARTLETT STREET

The Bartlett Street sub-catchment area represents a unique and compelling opportunity within the context of the Four Mile Run project. It is a sizable yet manageable sub-catchment area, within an urbanized, densely populated and highly visible city neighborhood.

More importantly, however, this sub-catchment area outlets directly to the headwaters of Panther Hollow Run, near the intersection of Bartlett Street and Serpentine Drive, and therefore may be among the easiest and most direct of the study areas to reconnect back into the historical stream network that runs through Schenley Park.

The storage potential within the sub-catchment area is relatively sparse, except perhaps for the area of Bartlett Street, immediately upstream of the Panther Hollow Run headwaters, and along Wightman Street. It is feasible in these areas to create subsurface detention underneath the rights-of-way, as well as convey surface runoff through a series of curbed stormwater planters and green intersections along the roadway.

Performance

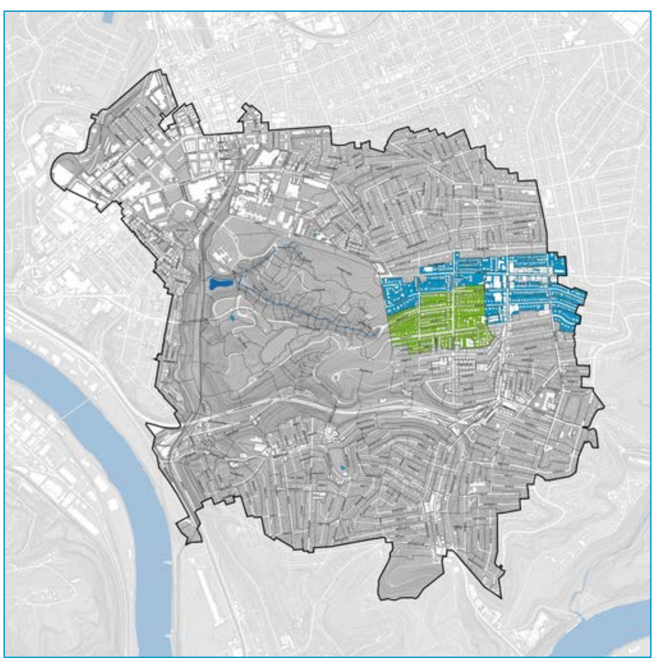
Impervious acres managed	18.1
Annual CSO Gallons Removed	11.9 MG

Cost Estimate

10 intersections @ $325,000	$3,250,000
2,640 ft ROW improvements @ $200	$528,000
71,784 cu ft stormwater storage @ $18	$1,292,122
100 downspout disconnections	$100,000
Total Cost Estimate	$5,170,112
Class 5 Cost Range	$2,585,056 - $10,340,225
$/Imp. Acre Managed	$143k - $570k
$/Gal	$0.22 - $0.87

Cost-Sharing Scenario

Class 5 Cost Range	$1,855,856 - $7,423,425
$/Imp. Acre man. w/ cost-share	$102k - $410k
$/Gal w/cost-sharing	$0.16 - $0.62



Locator Map

Sewer Network Map

Area	**187.3 acres**
Impervious area	**54.8 acres**
Percentage Impervious	**43%**
Impervious area managed	**18.1 acres**
Management Ratio	**33%**
1.5", 24hr impervious runoff total	**1,622,237 gallons**
1.5", 24 hr impervious runoff managed	**536,982 gallons**

9 | SQUIRREL HILL SOUTH AND GREENFIELD

The Squirrel Hill South and Greenfield catchment is a 325-acre, highly urbanized, residential neighborhood bisected by Beechwood Boulevard and Monitor Street. The land surface flows towards Beechwood Boulevard at the intersection with Forward Avenue. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system through the downstream catchment (Poccusset Street).

Connection to the Four Mile Run conveyance network could utilize one of the two sewer pipes under I-376. It may be possible to disconnect sewer flows from one pipe such that it could be dedicated to stormwater flows for a portion, connecting this large upper-shed catchment area to the network below. Alternatively, a horizontal directionally drilled pipe could convey these flows.

Considering the high-upfront cost of connecting this shed downstream, two strategies should be considered for this substantial sub-catchment area:

1. Consider a more ambitious management ratio of over 35%.
2. Evaluate segregating redundant sewer pipes under the I-376 Parkway East corridor.

Performance

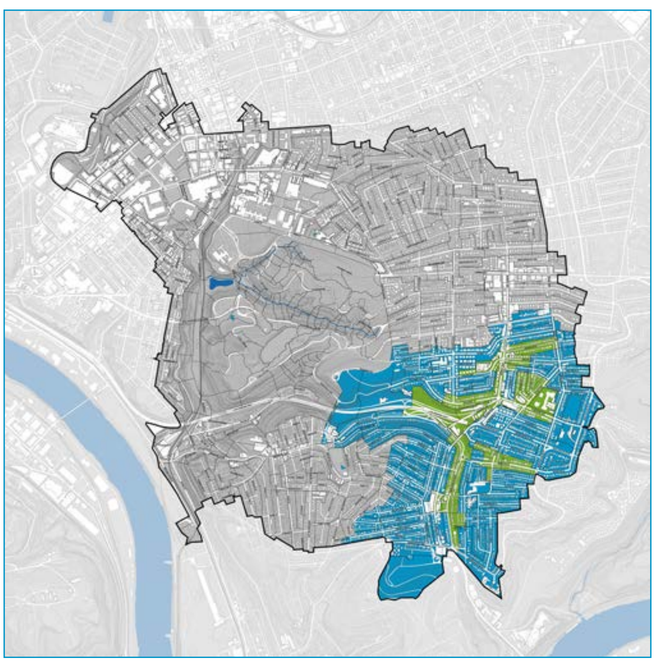
Impervious acres managed	38.3
Annual CSO Gallons Removed	25.1 MG

Cost Estimate

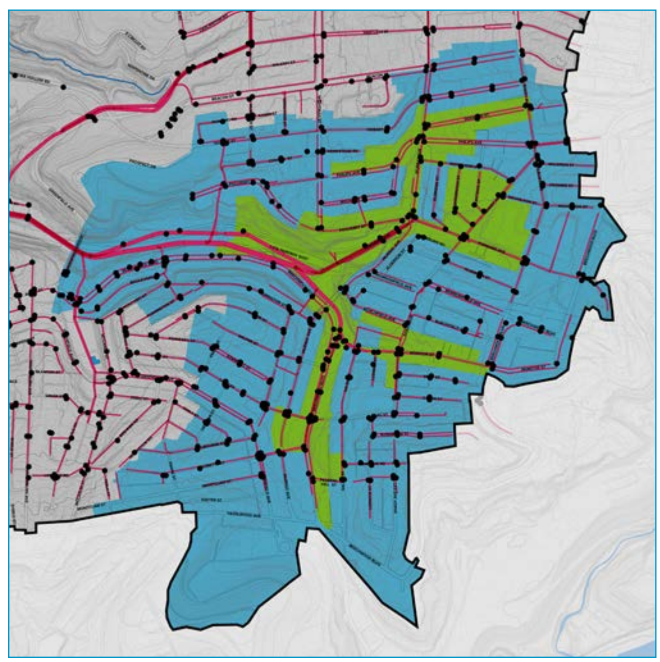
26 intersections @ $325,000	$8,450,000
10,560 ft ROW improvements @ $200	$2,112,000
187,403 cu ft stormwater storage @ $18	$3,373,258
2,640 ft of 48” HDD pipe	$5,068,800
250 downspout disconnections	$250,000
Total Cost Estimate	$19,254,058
Class 5 Cost Range	$9,627,029 - $38,508,116
$/Imp. Acre Managed	$251k - $1,005k
$/Gal	$0.38 - $1.53

Cost-Sharing Scenario

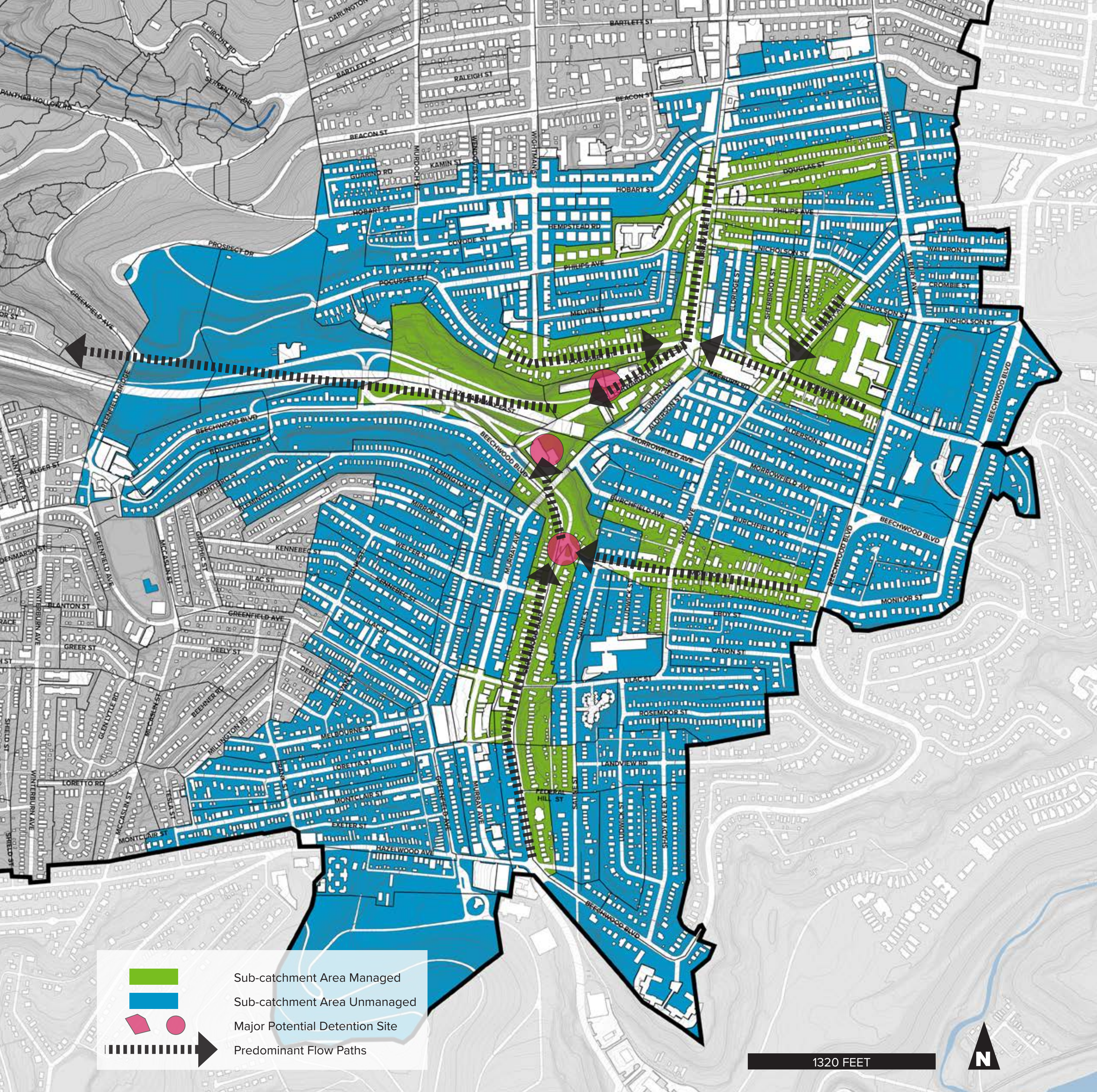
Class 5 Cost Range	$7,620,229 - $30,480,916
$/Imp. Acre man. w/ cost-share	$199k - $795k
$/Gal w/cost-sharing	$0.30 - $1.21



Locator Map



Sewer Network Map



Area	**627.8 acres**
Impervious area	**165.0 acres**
Percentage Impervious	**39%**
Impervious area managed	**38.3 acres**
Management Ratio	**23%**
1.5”, 24hr impervious runoff total	**6,035,356 gallons**
1.5”, 24 hr impervious runoff managed	**1,401,873 gallons**

10 | MAGEE FIELD

The Magee Field catchment is a 95-acre, highly urbanized, residential neighborhood draining to Saline Street. The land surface trends topographically north towards Saline Street/Interstate 376. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system through the downstream catchment (Saline Street).

Flows managed in the right-of-way could outlet/overflow back into the PWSA sewer system via an existing PWSA structure or alternatively conveyed towards Magee Field. One potential management concept is the installation of subsurface detention storage below the field. Magee Field is ideally situated near the downslope end of the catchment, providing a good opportunity to store substantial flows. This could potentially be a stand alone project coordinated with any improvements to the field in conjunction with DPW.

Performance

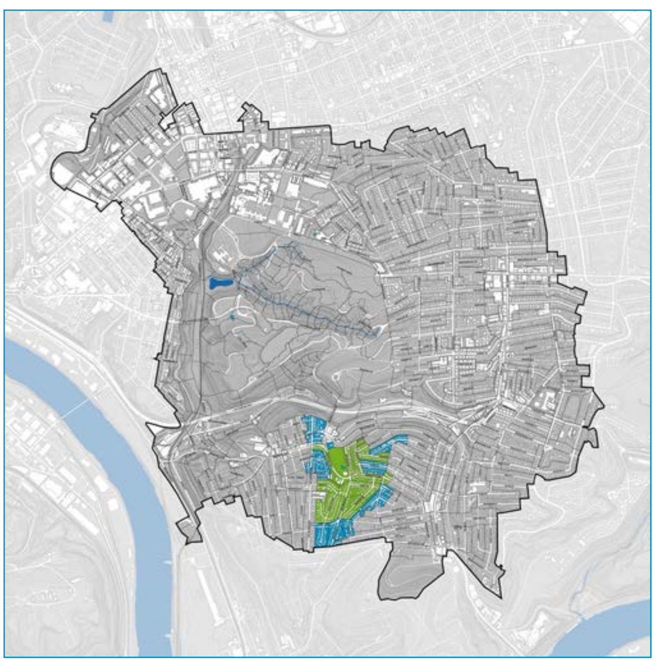
Impervious acres managed	12.6
Annual CSO Gallons Removed	8.2 MG

Cost Estimate

10 intersections @ $325,000	$3,250,000
5,280 ft ROW improvements @ $200	$1,056,000
60,372 cu ft stormwater storage @ $18	$1,086,689
57,000 sq ft playing field remediation	$855,000
60 downspout disconnections	$60,000
Total Cost Estimate	$6,307,689
Class 5 Cost Range	$3,153,845 - $12,615,379
$/Imp. Acre Managed	$251k - $1,003k
$/Gal	$0.38 - $1.53

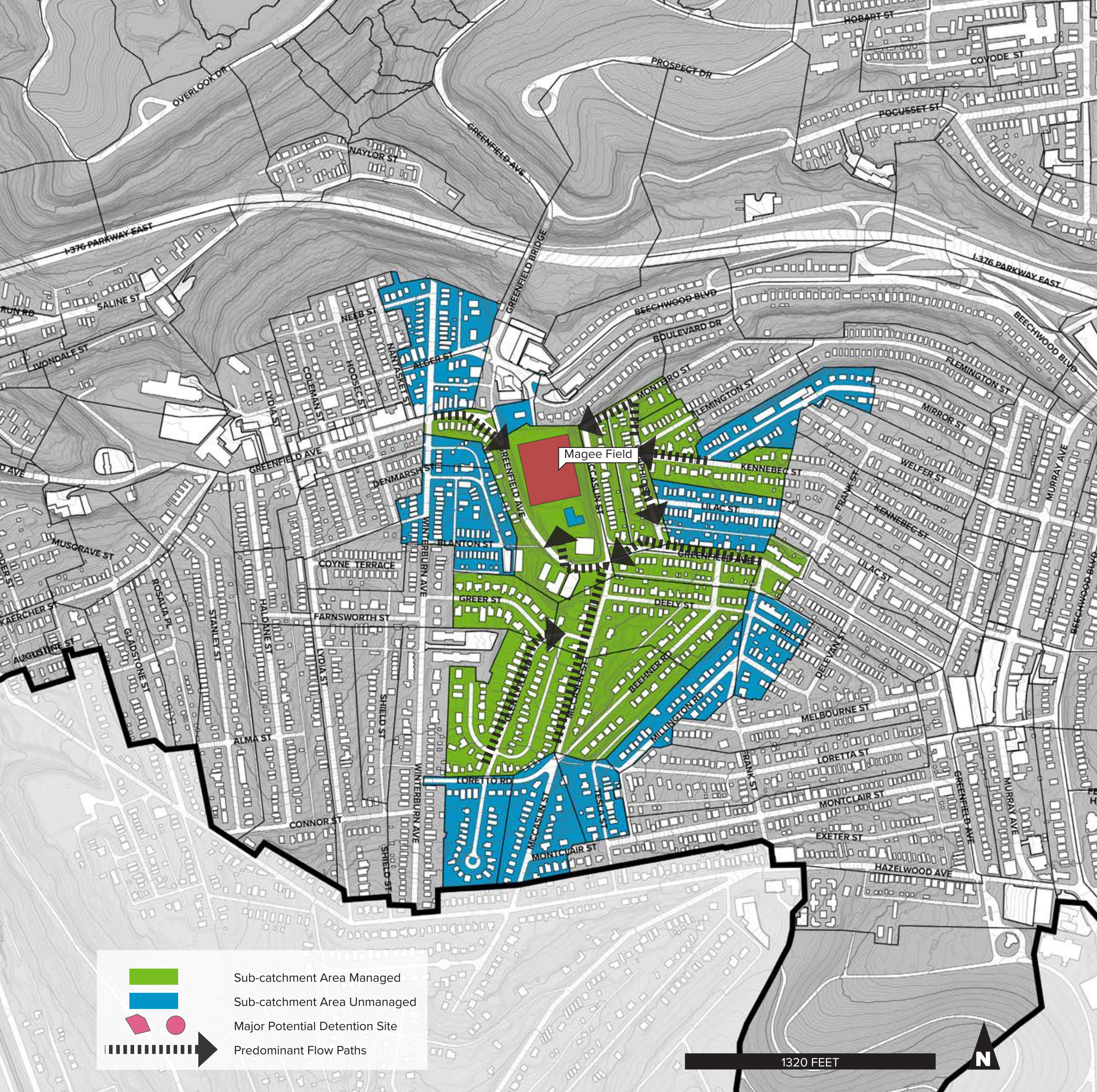
Cost-Sharing Scenario

Class 5 Cost Range	$2,131,695 - $8,526,779
$/Imp. Acre man. w/ cost-share	$169k - $678k
$/Gal w/cost-sharing	$0.26 - $1.03



Locator Map

Sewer Network Map



Area	**95.2 acres**
Impervious area	**24.1 acres**
Percentage Impervious	**38%**
Impervious area managed	**12.6 acres**
Management Ratio	**52%**
1.5”, 24hr impervious runoff total	**866,560 gallons**
1.5”, 24 hr impervious runoff managed	**451,611 gallons**

11 | GREENFIELD SCHOOL

The Greenfield School catchment is a small area perched on top of a hill that is hydrologically isolated from other parts of Greenfield.

There is the possibility of creating a new conveyance connection to the valley below from behind Greenfield School down to Saline Street.

The size of this shed and the relatively high upfront cost of managing its stormwater here gives it a rather unfavorable cost to performance ratio. Nevertheless, improvements could occur at a later date and in coordination with other improvements that are planned. For instance, DOMI could take on 100% of the right-of-way costs in this area by adopting PWSA's stormwater details as part of its practices.

Performance

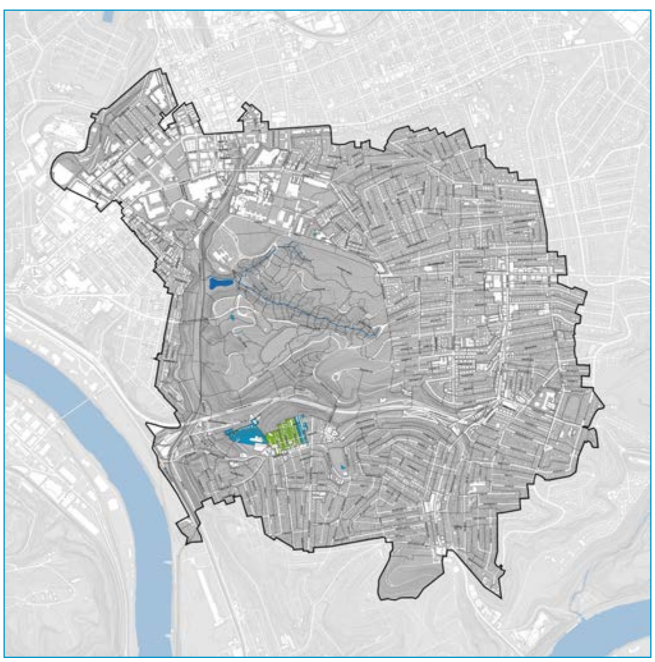
Impervious acres managed	3.7
Annual CSO Gallons Removed	2.4 MG

Cost Estimate

2 intersections @ $325,000	$650,000
1,320 ft conveyance @ $600	$792,000
1,320 ft ROW improvements @ $200	$264,000
17,921 cu ft stormwater storage @ $18	$322,577
20 downspout disconnections	$20,000
Total Cost Estimate	$2,048,577
Class 5 Cost Range	$1,024,288 - $4,097,153
$/Imp. Acre Managed	$278k - $1,113k
$/Gal	$0.42 - $1.70

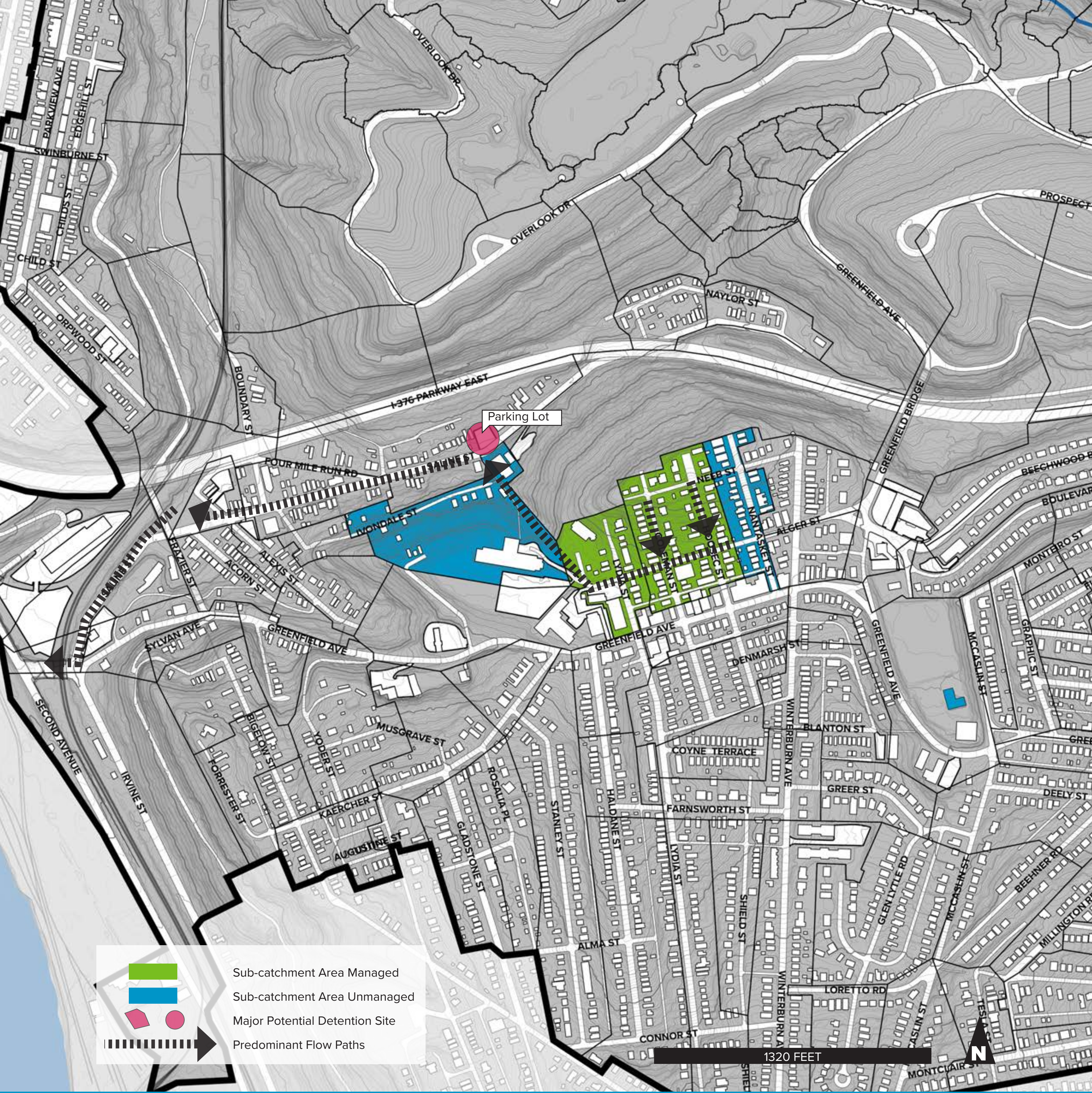
Cost-Sharing Scenario

Class 5 Cost Range	$815,088 - $3,260,353
$/Imp. Acre man. w/ cost-share	$221k - $885k
$/Gal w/cost-share	$0.34 - $1.35



Locator Map

Sewer Network Map



Area	**22.6 acres**
Impervious area	**6.2 acres**
Percentage Impervious	**41%**
Impervious area managed	**3.7 acres**
Management Ratio	**60%**
1.5", 24hr impervious runoff total	**224,632 gallons**
1.5", 24 hr impervious runoff managed	**134,058 gallons**

12 | GREENFIELD AVENUE

The Greenfield Avenue South catchment is a 97-acre, moderately urbanized, residential neighborhood draining to Saline Street. The land surface flows through the right-of-way of Greenfield Avenue to the intersection with Saline Street. Stormwater runoff is presently intercepted by catch basins and conveyed via the PWSA combined sewer system.

Disconnection of this sub-catchment area is dependent on the Four Mile Run conveyance network passing through the Run neighborhood through Four Mile Run Park. Runoff would likely be managed in the ROW with excess discharging back into the PWSA combined sewer system. Stormwater would follow Greenfield Avenue and then drop into the Four Mile Run valley near the top of Alexis Street and then follow Alexis Street to Four Mile Run Park.

The size of this shed and the relatively high upfront cost of managing its stormwater gives it a rather unfavorable cost to performance ratio. Nevertheless, improvements could occur at a later date and in coordination with other improvements that are planned. For instance, DOMI could take on 100% of the right-of-way costs in this area by adopting PWSA's stormwater details as part of its practices.

Performance

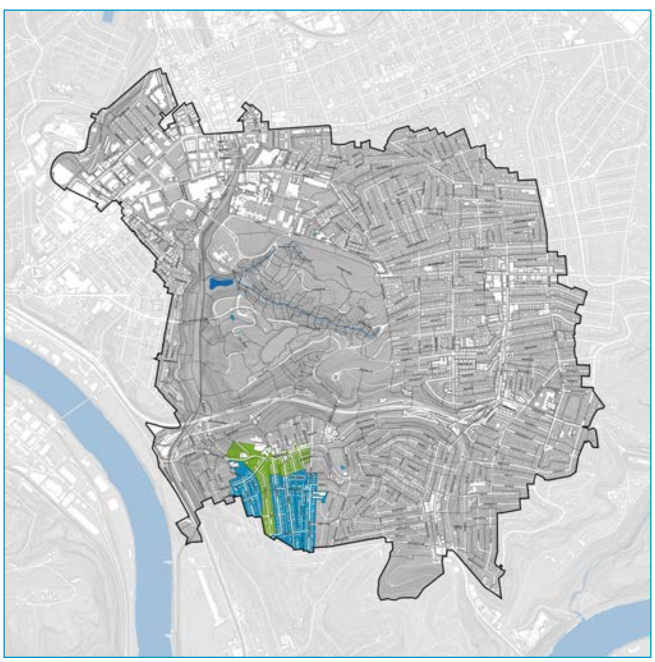
Impervious acres managed	10.1
Annual CSO Gallons Removed	6.6 MG

Cost Estimate

8 intersections @ $325,000	$2,600,000
1,320 ft conveyance @ $600	$792,000
5,280 ft ROW improvements @ $200	$1,056,000
48,202 cu ft stormwater storage @ $18	$867,645
60 downspout disconnections	$60,000
Subtotal	$5,375,645
Class 5 Cost Range	$2,687,822 - $10,751,290
$/Imp. Acre Managed	$267k - $1,069k
$/Gal	$0.41 - $1.63

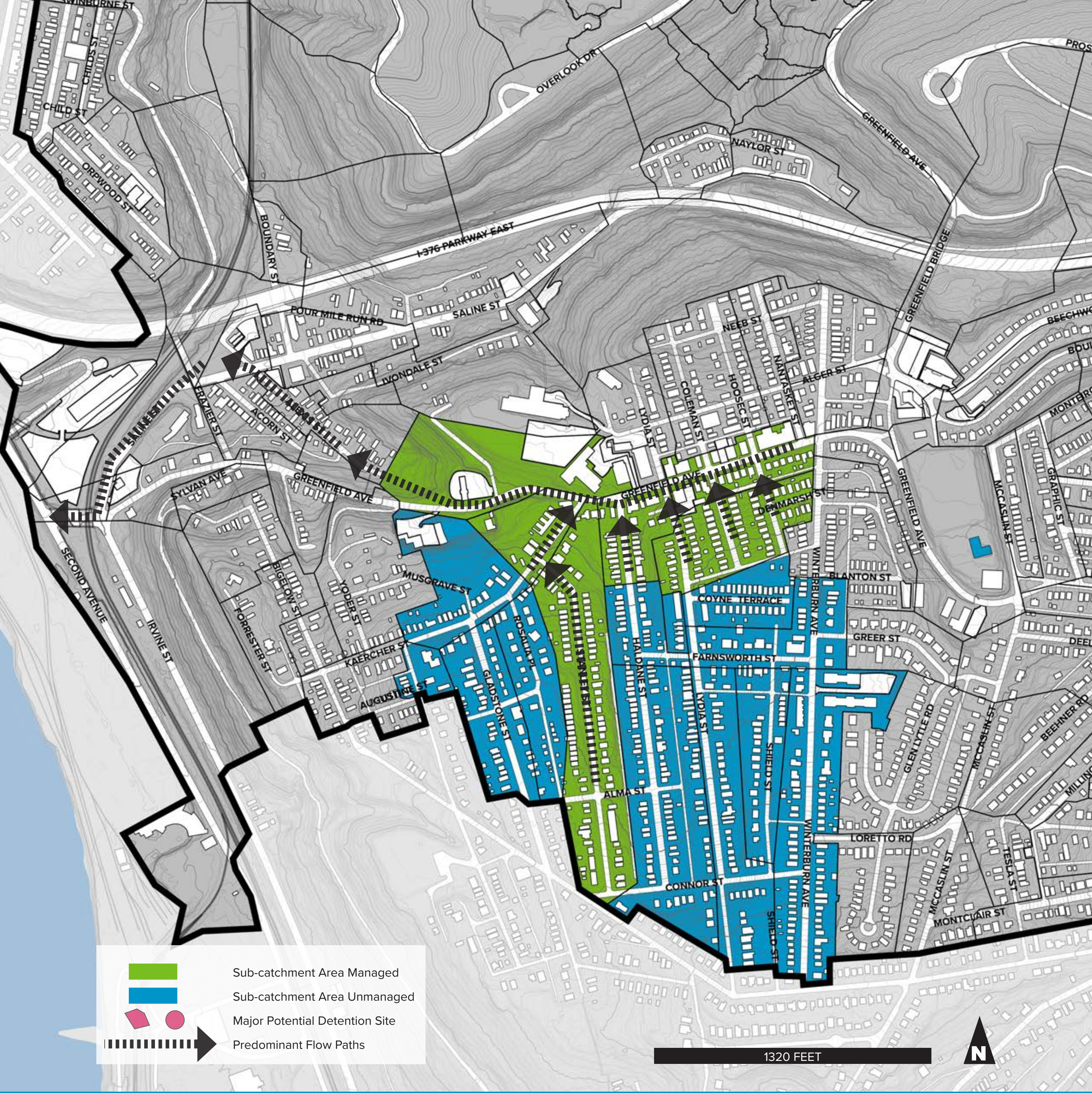
Cost-Sharing Scenario

Class 5 Cost Range	$1,969,822 - $7,879,290
$/Imp. Acre man. w/ cost-share	$196k - $783k
$/Gal w/cost-sharing	$0.30 - $1.20



Locator Map

Sewer Network Map



Area	**97.0 acres**
Impervious area	**24.5 acres**
Percentage Impervious	**37%**
Impervious area managed	**10.1 acres**
Management Ratio	**41%**
1.5", 24hr impervious runoff total	**877,754 gallons**
1.5", 24 hr impervious runoff managed	**360,580 gallons**

13 | IRVINE STREET

The Irvine Street catchment is a 52-acre, largely sloped area very near to the Four Mile Run project's connection point with the Monongahela. Runoff from the steep slopes could be captured along Irvine Street and Greenfield Avenue and conveyed to the river without substantial investment.

The Sylvan Street Right-of-Way is situated on a shelf about halfway up the steep slope. This could be an opportunity for a former street to be re-utilized for capture and conveyance of stormwater. Such an improvement could be aligned with the southeastern branch of the proposed Mon-Oakland Connector.

Performance

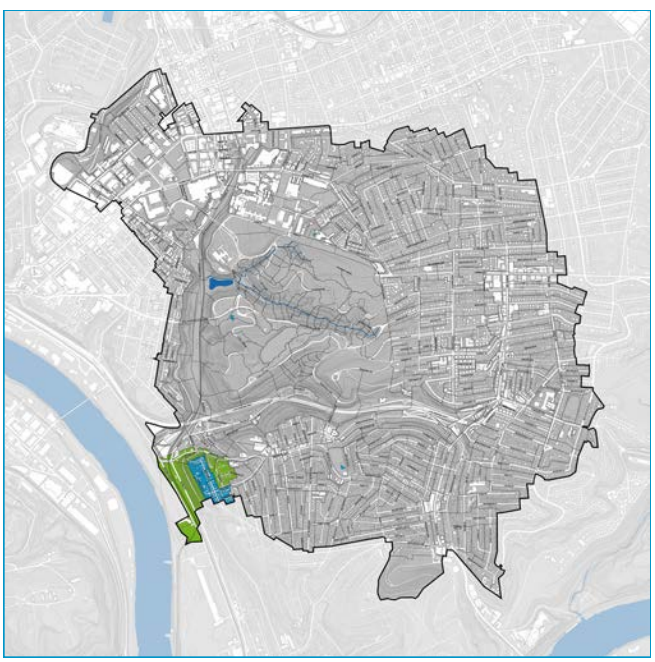
Impervious acres managed	6.9
Annual CSO Gallons Removed	4.5 MG

Cost Estimate

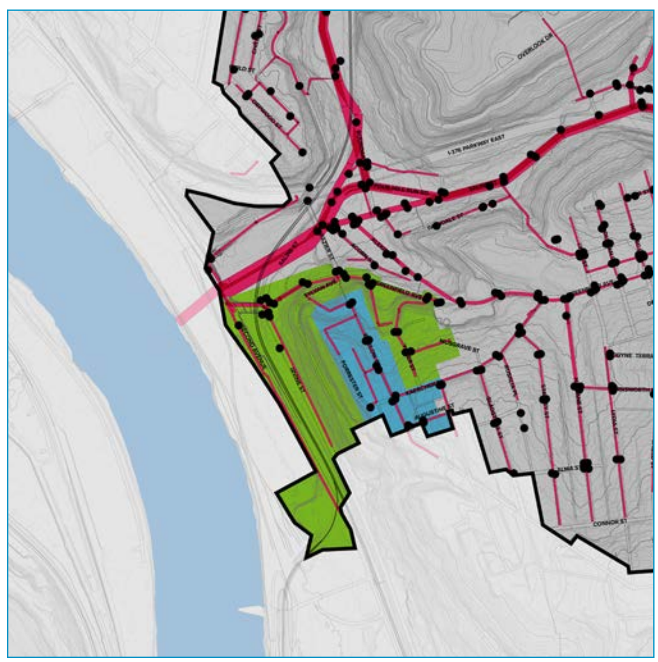
2 intersections @ $325,000	$650,000
2,640 ft ROW improvements @ $200	$528,000
41,657 cu ft stormwater storage @ $18	$749,822
20 downspout disconnections	$20,000
Total Cost Estimate	$1,947,822
Class 5 Cost Range	$973,911 - $3,895,644
$/Imp. Acre Managed	$141k - $563k
$/Gal	$0.21 - $0.86

Cost-Sharing Scenario

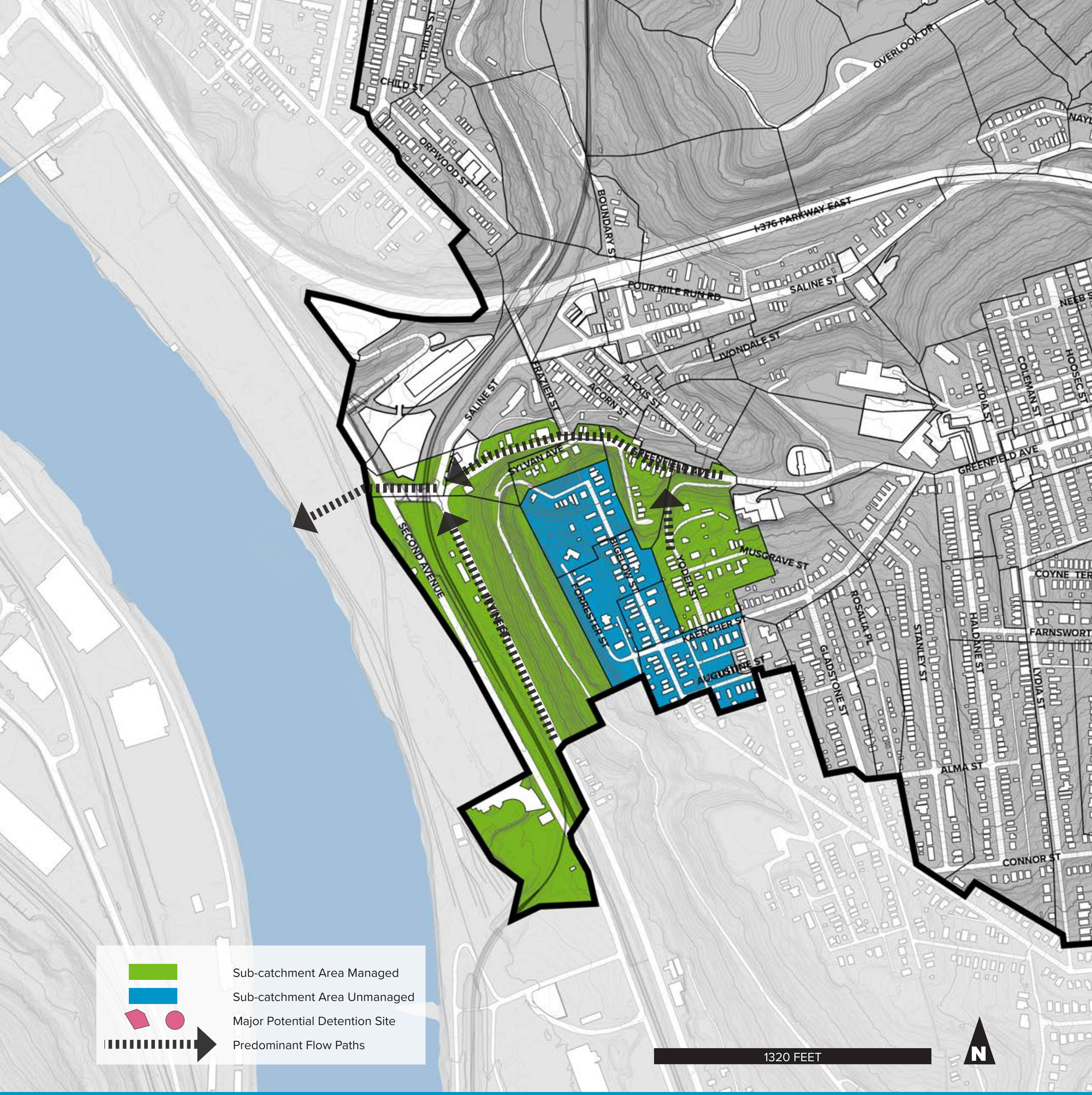
Class 5 Cost Range	$764,711 - $3,058,844
$/Imp. Acre man. w/ cost-share	$111k - $442k
$/Gal w/cost-sharing	$0.17 - $0.67



Locator Map



Sewer Network Map



Area	**52.4 acres**
Impervious area	**14.4 acres**
Percentage Impervious	**28%**
Impervious area managed	**10.3 acres**
Management Ratio	**71%**
1.5”, 24hr impervious runoff total	**437,575 gallons**
1.5”, 24 hr impervious runoff managed	**311,614 gallons**


Monongahela River

4

Expansion Summary

Map of showing areas where impervious acres are managed in this scenario.

Summary

The Four Mile Run project enables a shed-wide green infrastructure network that can handle substantial amounts of stormwater and thus effect a sizable reduction in combined-sewer overflow volume. Based on the results in a presentation by Mott MacDonald on 05 April 2019, the core project reduces combined-sewer overflow by 41 million gallons annually.

The watershed expansion scenario in this memorandum leads to a total CSO reduction of 158 million gallons annually, per the 05 April 2019 SWMM presentation by Mott MacDonald. This level of CSO reduction would be a major step toward PWSA's compliance goals. A more ambitious management scenario in these sheds remains possible and would further enhance performance. For the purposes of this memorandum, only one management scenario was modeled.

The tables on the following pages demonstrate the cumulative effect of adding each sub-catchment's cost and performance together. Cost scenarios with and without cost-sharing are compared side-by-side. Three cost-basis contingency factors were evaluated:

- Table 4.1 and Table 4.2 use the lowest Class 5 cost estimate which is cost minus 50%. This is the bare minimum cost.
- Table 4.3 and Table 4.4 use the best estimate cost which is cost plus 30% contingency per PWSA's Interim Stormwater Program Manager. These tables represent the cost estimates with the highest degree of confidence by the Watershed Expansion Team.
- Table 4.5 and Table 4.6 use the highest Class 5 cost estimate which is cost plus 100%. This is the absolute maximum cost.

Table 4.7 and figures 4.2 and 4.3 are derived from the 05 April 2019 SWMM presentation by Mott MacDonald and demonstrate the flood risk reduction benefits conferred by the core project and the watershed expansion. Table 4.7 shows that the core project and watershed expansion can reduce flood volumes by over 50%. Benefits of flood risk reduction have not been assigned a dollar value at this time.

The Devil is in the Details

Costs remain a significant point of scrutiny. At Class 5 estimate precision, the upper bounds of possible costs are still well outside of PWSA's comfort zone. Experience at other on-going PWSA design projects elsewhere in the city is illustrating the challenges in isolating implementation costs of GSI components with pre-defined performance parameters. The complexity of Pittsburgh's sub-surface infrastructure requires a great deal of contortion to accommodate new GSI features while avoiding the introduction of utility conflicts, protecting existing trees, minimizing the risk of basement intrusion from saturated soils, meeting ADA requirements, and respecting private property concerns. Costs are inflated by the need for extensive pot-holing and hand excavation to confirm the presence of buried utilities and by the prevalence of decommissioned utility lines that were never removed and are not marked out by PA One Call.

New subsurface storage and conveyance features to be retrofitted within developed areas are often constrained from extending continuously because of conflicts under the ROW, thus requiring design of separate "cells" or features that extend for only a short distance, and increasing the cost of construction. Walls, fences, pavements and landscaping on private property frequently extend to the edge of sidewalk, sometimes encroaching on the public ROW and limiting the availability of space or opportunities to enhance connectivity. Furthermore, roadway repaving practices have largely eliminated the curb reveal in many places, which introduces an additional set of complications regarding the roadway and gutter elevations. None of these conditions can be easily anticipated in advance of land and subsurface survey work, and additional change orders are always likely when working in uncertain conditions.

Providing reliable cost estimates for retrofitting developed areas is also made more difficult by the absence of established design components and approved techniques. Costing rules-of-thumb established in other cities do not always represent Pittsburgh's physical constraints, including topography, clay soils, and landslide prone slopes. Thus far, each GSI design project in the city has its own set of structures and practices tailored to address site-specific conditions.

Without standard design details and acceptable practices, reliably identifying project costs becomes a challenge at both the planning and design stages. Until Pittsburgh establishes its own design guidelines for implementing GSI retrofits, there will necessarily remain a high degree of uncertainty in establishing overall project costs. An additional challenge siting GSI within Pittsburgh developed areas has been including actual green features, which get cut back due to cost or spatial limitations. Residents are protective of parking spaces (which precludes the use of bump outs). Land use competition with ADA standards, sidewalk infrastructure and existing trees, have substantially limited the footprints available for plantings. At many project sites, this has forced a reliance on permeable pavements and subsurface storage to meet interception needs, resulting in "green" projects with no green components.

Shared Benefits, Shared Costs

Green infrastructure has long been heralded as a stormwater management solution that is cost-effective and environmentally sensitive while providing benefits to the communities within which it is implemented. Those secondary benefits, such as improved roadways, improved access and accessibility, improved streetscapes, improved green space, flood risk reduction, and improved property values, largely accrue to entities other than PWSA. In many cases, green infrastructure implementation leads to restoration of assets such as roadways, sidewalks, and park amenities. These secondary benefits should not be entirely funded by PWSA, whose green infrastructure motivation is CSO reduction first and foremost.

For the purposes of discussion, this memorandum evaluated a cost-sharing scenario whereby those secondary benefits were segregated from the costs associated with stormwater performance. When these cost shares are taken into account, the network becomes quite affordable.

Cost-sharing of course involves close coordination between partners. All parties, including utilities, roadway owners, major roadway uses such as the transit agency, and private property owners, need to have an intimate understanding of each other's long-term infrastructure plans.

Figure 4.1 Dig-once was deliberate policy of the City in the early 20th century. When a street was opened, re-openings were prohibited for a period of five years to minimize disturbances and to encourage project alignment between utilities and private property owners. Photo from N. Highland Avenue, East Liberty, 1922, Pittsburgh City Photographer Collection.

A coordinated approach would ideally lead to a "dig-once" policy whereby all infrastructure improvements to a given street are accomplished comprehensively at one time. Such a policy compels all parties to the table and discourages disruptions after substantial improvements have been made. PWSA and its partners can look to historical precedent where DPW forbade street openings for five years after major construction during the early 20th century, a time of significant infrastructure implementation.

Based on this analysis, further refinement of cost assumptions and planning must go hand in hand with cost-sharing discussions and commitments to coordination at the highest level. Now is the time for PWSA to develop its case for close collaboration with its partners to build the clean and green public infrastructure of the future.

Summary (continued)

Table 4.1 Sub-catchment Phasing: Lowest Class 5 Costs

Cost minus 50% per AACE Class 5 cost estimation precision

#	Area Name	Catchment Imp. Acres Managed[i]	Cumulative Imp. Acres Managed	Catchment CSO Gallons Removed Annually	Cumulative CSO Gallons Removed Annually	Catchment Capital Cost	Cumulative Capital Cost	Catchment Cost per Imp. Acre Managed	Cumulative Cost per Imp. Acre Managed	Catchment Cost per gallon CSO removed	Cumulative Cost per gallon CSO removed
1	Project Catchment Area	59.0	59.0	41,000,000	41,000,000	$8,100,000 [ii]	$8,100,000	$137k	$137k	$0.20	$0.20
2	Phipps Conservatory	0.0	59.0	0	41,000,000		$8,100,000		$137k		$0.20
3	South Oakland	7.3	66.3	4,812,073	45,812,073	$1,506,325	$9,606,325	$205k	$145k	$0.31	$0.21
4	Oakland	40.5	106.9	26,568,627	72,380,700	$6,581,239	$16,187,563	$162k	$151k	$0.25	$0.22
5	Carnegie Mellon	22.0	128.9	14,431,440	86,812,139	$4,589,699	$20,777,263	$209k	$161k	$0.32	$0.24
6	Forbes Avenue	8.1	137.0	5,314,024	92,126,163	$1,930,673	$22,707,936	$238k	$166k	$0.36	$0.25
7	Squirrel Hill North	14.1	151.1	9,274,358	101,400,521	$3,072,477	$25,780,413	$217k	$171k	$0.33	$0.25
8	Bartlett Street	18.1	169.3	11,884,654	113,285,175	$2,585,056	$28,365,469	$143k	$168k	$0.22	$0.25
9	Squirrel Hill South and Greenfield	38.3	207.6	25,124,987	138,410,162	$9,627,029	$37,992,498	$251k	$183k	$0.38	$0.27
10	Magee Field	12.6	220.2	8,249,556	146,659,718	$3,153,845	$41,146,343	$251k	$187k	$0.38	$0.28
11	Greenfield School	3.7	223.8	2,414,944	149,074,662	$1,024,288	$42,170,631	$278k	$188k	$0.42	$0.28
12	Greenfield Avenue	10.1	233.9	6,592,129	155,666,791	$2,687,822	$44,858,454	$267k	$192k	$0.41	$0.29
13	Irvine Street	6.9	240.8	4,534,552	160,201,343	$973,911	$45,832,365	$141k	$190k	$0.21	$0.29
	Total - Estimated[iii]				160,201,343		$45,832,365				$0.29
	Total - Modeled[iv v]		240.8		158,000,000		$45,832,365		$190k		$0.29

i Refers to model-equivalent impervious acres managed.

ii Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%.

iii Estimated using model-equivalent impervious acre to CSO million gallons managed conversion factor of 0.6556 based on SWMM results from 05 April 2019 presentation by Mott MacDonald. Estimated model-equivalent impervious acres use GIS impervious acres to model-equivalent conversion factor of 0.6741. This estimation methodology is explained in Chapter 3.

iv Per 05 April 2019 presentation by Mott MacDonald.

v Estimated and Modeled differ due to a series of rounding errors. The modeled CSO volume removed is 0.01% smaller than the estimate in this memorandum, well within the assumed range of error for the SWMM model. This difference has a negligible impact on the cost per gallon metric.

Less than or equal to $250,000/imp. acre

$250,000/imp. acre - $432,000/imp. acre

Greater than $432,000/imp. acre

Less than or equal to $0.75/gallon

$0.76/gallon - $0.89/gallon

Greater than $0.90/gallon

Table 4.2 Sub-catchment Phasing: Lowest Class 5 Costs w/ cost-sharing

Cost minus 50% per AACE Class 5 cost estimation precision

#	Area Name	Catchment Imp. Acres Managed[i]	Cumulative Imp. Acres Managed	Catchment CSO Gallons Removed Annually	Cumulative CSO Gallons Removed Annually	Catchment Capital Cost	Cumulative Capital Cost	Catchment Cost per Imp. Acre Managed	Cumulative Cost per Imp. Acre Managed	Catchment Cost per gallon CSO removed	Cumulative Cost per gallon CSO removed
1	Project Catchment Area	59.0	59.0	41,000,000	41,000,000	$8,100,000[ii]	$8,100,000	$137k	$137k	$0.20	$0.20
2	Phipps Conservatory	0.0	59.0	0	41,000,000		$8,100,000		$137k		$0.20
3	South Oakland	7.3	66.3	4,812,073	45,812,073	$1,167,125	$9,267,125	$159k	$140k	$0.24	$0.20
4	Oakland	40.5	106.9	26,568,627	72,380,700	$5,083,239	$14,350,363	$125k	$134k	$0.19	$0.20
5	Carnegie Mellon	22.0	128.9	14,431,440	86,812,139	$4,160,099	$18,510,463	$189k	$144k	$0.29	$0.21
6	Forbes Avenue	8.1	137.0	5,314,024	92,126,163	$1,331,473	$19,841,936	$164k	$145k	$0.25	$0.22
7	Squirrel Hill North	14.1	151.1	9,274,358	101,400,521	$2,134,077	$21,976,013	$151k	$145k	$0.23	$0.22
8	Bartlett Street	18.1	169.3	11,884,654	113,285,175	$1,855,856	$23,831,869	$102k	$141k	$0.16	$0.21
9	Squirrel Hill South and Greenfield	38.3	207.6	25,124,987	138,410,162	$7,620,229	$31,452,098	$199k	$152k	$0.30	$0.23
10	Magee Field	12.6	220.2	8,249,556	146,659,718	$2,131,695	$33,583,793	$169k	$153k	$0.26	$0.23
11	Greenfield School	3.7	223.8	2,414,944	149,074,662	$815,088	$34,398,881	$221k	$154k	$0.34	$0.23
12	Greenfield Avenue	10.1	233.9	6,592,129	155,666,791	$1,969,822	$36,368,704	$196k	$155k	$0.30	$0.23
13	Irvine Street	6.9	240.8	4,534,552	160,201,343	$764,711	$37,133,415	$111k	$154k	$0.17	$0.23
	Total - Estimated[iii]				160,201,343		$37,133,415				$0.23
	Total - Modeled[iv v]		240.8		158,000,000		$37,133,415		$154k		$0.24

i Refers to model-equivalent impervious acres managed.

ii Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%.

iii Estimated using model-equivalent impervious acre to CSO million gallons managed conversion factor of 0.6556 based on SWMM results from 05 April 2019 presentation by Mott MacDonald. Estimated model-equivalent impervious acres use GIS impervious acres to model-equivalent conversion factor of 0.6741. This estimation methodology is explained in Chapter 3.

iv Per 05 April 2019 presentation by Mott MacDonald.

v Estimated and Modeled differ due to a series of rounding errors. The modeled CSO volume removed is 0.01% smaller than the estimate in this memorandum, well within the assumed range of error for the SWMM model. This difference has a negligible impact on the cost per gallon metric.

Less than or equal to $250,000/imp. acre

$250,000/imp. acre - $432,000/imp. acre

Greater than $432,000/imp. acre

Less than or equal to $0.75/gallon

$0.76/gallon - $0.89/gallon

Greater than $0.90/gallon

Summary (continued)

Table 4.3 Sub-catchment Phasing: Best Estimate Costs

Cost plus 30% contingency per PWSA's Interim Stormwater Program Manager[i]

#	Area Name	Catchment Imp. Acres Managed[ii]	Cumulative Imp. Acres Managed	Catchment CSO Gallons Removed Annually	Cumulative CSO Gallons Removed Annually	Catchment Capital Cost	Cumulative Capital Cost	Catchment Cost per Imp. Acre Managed	Cumulative Cost per Imp. Acre Managed	Catchment Cost per gallon CSO removed	Cumulative Cost per gallon CSO removed
1	Project Catchment Area	59.0	59.0	41,000,000	41,000,000	$14,040,000 [iii]	$14,040,000	$238k	$238k	$0.34	$0.34
2	Phipps Conservatory	0.0	59.0	0	41,000,000	$-	$14,040,000		$238k		$0.34
3	South Oakland	7.3	66.3	4,812,073	45,812,073	$3,916,445	$17,956,445	$534k	$271k	$0.81	$0.39
4	Oakland	40.5	106.9	26,568,627	72,380,700	$17,111,220	$35,067,665	$422k	$328k	$0.64	$0.48
5	Carnegie Mellon	22.0	128.9	14,431,440	86,812,139	$11,933,218	$47,000,883	$542k	$365k	$0.83	$0.54
6	Forbes Avenue	8.1	137.0	5,314,024	92,126,163	$5,019,751	$52,020,634	$619k	$380k	$0.94	$0.56
7	Squirrel Hill North	14.1	151.1	9,274,358	101,400,521	$7,988,441	$60,009,075	$565k	$397k	$0.86	$0.59
8	Bartlett Street	18.1	169.3	11,884,654	113,285,175	$6,721,146	$66,730,221	$371k	$394k	$0.57	$0.59
9	Squirrel Hill South and Greenfield	38.3	207.6	25,124,987	138,410,162	$25,030,275	$91,760,496	$653k	$442k	$1.00	$0.66
10	Magee Field	12.6	220.2	8,249,556	146,659,718	$8,199,996	$99,960,492	$652k	$454k	$0.99	$0.68
11	Greenfield School	3.7	223.8	2,414,944	149,074,662	$2,663,150	$102,623,642	$723k	$458k	$1.10	$0.69
12	Greenfield Avenue	10.1	233.9	6,592,129	155,666,791	$6,988,338	$109,611,980	$695k	$469k	$1.06	$0.70
13	Irvine Street	6.9	240.8	4,534,552	160,201,343	$2,532,169	$112,144,149	$366k	$466k	$0.56	$0.70
	Total - Estimated[iv]				160,201,343		$112,144,149				$0.70
	Total - Modeled[v vi]		240.8		158,000,000		$112,144,149		$466k		$0.71

i Base cost with +30% contingency was suggested at a working meeting on 08 March 2019 at PWSA.

ii Refers to model-equivalent impervious acres managed.

iii Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%. With this range in mind, CEC's base estimate is therefore $10,800,000. Adding +30% equals $14,040,000.

iv Estimated using model-equivalent impervious acre to CSO million gallons managed conversion factor of 0.6556 based on SWMM results from 05 April 2019 presentation by Mott MacDonald. Estimated model-equivalent impervious acres use GIS impervious acres to model-equivalent conversion factor of 0.6741. This estimation methodology is explained in Chapter 3.

v Per 05 April 2019 presentation by Mott MacDonald.

vi Estimated and Modeled differ due to a series of rounding errors. The modeled CSO volume removed is 0.01% smaller than the estimate in this memorandum, well within the assumed range of error for the SWMM model. This difference has a negligible impact on the cost per gallon metric.

(green) Less than or equal to $250,000/imp. acre	(green) Less than or equal to $0.75/gallon
(orange) $250,000/imp. acre - $432,000/imp. acre	(orange) $0.76/gallon - $0.89/gallon
(red) Greater than $432,000/imp. acre	(red) Greater than $0.90/gallon

Table 4.4 Sub-catchment Phasing: Best Estimate Costs w/ cost-sharing

Cost plus 30% contingency per PWSA's Interim Stormwater Program Manager [i]

#	Area Name	Catchment Imp. Acres Managed[ii]	Cumulative Imp. Acres Managed	Catchment CSO Gallons Removed Annually	Cumulative CSO Gallons Removed Annually	Catchment Capital Cost	Cumulative Capital Cost	Catchment Cost per Imp. Acre Managed	Cumulative Cost per Imp. Acre Managed	Catchment Cost per gallon CSO removed	Cumulative Cost per gallon CSO removed
1	Project Catchment Area	59.0	59.0	41,000,000	41,000,000	$14,040,000 [iii]	$14,040,000	$238k	$238k	$0.34	$0.34
2	Phipps Conservatory	0.0	59.0	0	41,000,000	$-	$14,040,000		$238k		$0.34
3	South Oakland	7.3	66.3	4,812,073	45,812,073	$3,034,525	$17,074,525	$413k	$257k	$0.63	$0.37
4	Oakland	40.5	106.9	26,568,627	72,380,700	$13,216,420	$30,290,945	$326k	$283k	$0.50	$0.42
5	Carnegie Mellon	22.0	128.9	14,431,440	86,812,139	$10,816,258	$41,107,203	$491k	$319k	$0.75	$0.47
6	Forbes Avenue	8.1	137.0	5,314,024	92,126,163	$3,461,831	$44,569,034	$427k	$325k	$0.65	$0.48
7	Squirrel Hill North	14.1	151.1	9,274,358	101,400,521	$5,548,601	$50,117,635	$392k	$332k	$0.60	$0.49
8	Bartlett Street	18.1	169.3	11,884,654	113,285,175	$4,825,226	$54,942,861	$266k	$325k	$0.41	$0.48
9	Squirrel Hill South and Greenfield	38.3	207.6	25,124,987	138,410,162	$19,812,595	$74,755,456	$517k	$360k	$0.79	$0.54
10	Magee Field	12.6	220.2	8,249,556	146,659,718	$5,542,406	$80,297,862	$440k	$365k	$0.67	$0.55
11	Greenfield School	3.7	223.8	2,414,944	149,074,662	$2,119,230	$82,417,092	$575k	$368k	$0.88	$0.55
12	Greenfield Avenue	10.1	233.9	6,592,129	155,666,791	$5,121,538	$87,538,630	$509k	$374k	$0.78	$0.56
13	Irvine Street	6.9	240.8	4,534,552	160,201,343	$1,988,249	$89,526,879	$287k	$372k	$0.44	$0.56
	Total - Estimated[iv]				160,201,343		$89,526,879				$0.56
	Total - Modeled[v] [vi]		240.8		158,000,000		$89,526,879		$372k		$0.57

i Base cost with +30% contingency was suggested at a working meeting on 08 March 2019 at PWSA.

ii Refers to model-equivalent impervious acres managed.

iii Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%. With this range in mind, CEC's base estimate is therefore $10,800,000. Adding +30% equals $14,040,000.

iv Estimated using model-equivalent impervious acre to CSO million gallons managed conversion factor of 0.6556 based on SWMM results from 05 April 2019 presentation by Mott MacDonald. Estimated model-equivalent impervious acres use GIS impervious acres to model-equivalent conversion factor of 0.6741. This estimation methodology is explained in Chapter 3.

v Per 05 April 2019 presentation by Mott MacDonald.

vi Estimated and Modeled differ due to a series of rounding errors. The modeled CSO volume removed is 0.01% smaller than the estimate in this memorandum, well within the assumed range of error for the SWMM model. This difference has a negligible impact on the cost per gallon metric.

Less than or equal to $250,000/imp. acre

$250,000/imp. acre - $432,000/imp. acre

Greater than $432,000/imp. acre

Less than or equal to $0.75/gallon

$0.76/gallon - $0.89/gallon

Greater than $0.90/gallon

Summary (continued)

Table 4.5 Sub-catchment Phasing: Highest Class 5 Costs

Cost plus 100% per AACE Class 5 cost estimation precision

#	Area Name	Catchment Imp. Acres Managed[i]	Cumulative Imp. Acres Managed	Catchment CSO Gallons Removed Annually	Cumulative CSO Gallons Removed Annually	Catchment Capital Cost	Cumulative Capital Cost	Catchment Cost per Imp. Acre Managed	Cumulative Cost per Imp. Acre Managed	Catchment Cost per gallon CSO removed	Cumulative Cost per gallon CSO removed
1	Project Catchment Area	59.0	59.0	41,000,000	41,000,000	$16,200,000[ii]	$16,200,000	$275k	$275k	$0.40	$0.40
2	Phipps Conservatory	0.0	59.0	0	41,000,000	$-	$16,200,000		$275k		$0.40
3	South Oakland	7.3	66.3	4,812,073	45,812,073	$6,025,299	$22,225,299	$821k	$335k	$1.25	$0.49
4	Oakland	40.5	106.9	26,568,627	72,380,700	$26,324,954	$48,550,254	$650k	$454k	$0.99	$0.67
5	Carnegie Mellon	22.0	128.9	14,431,440	86,812,139	$18,358,796	$66,909,050	$834k	$519k	$1.27	$0.77
6	Forbes Avenue	8.1	137.0	5,314,024	92,126,163	$7,722,694	$74,631,744	$953k	$545k	$1.45	$0.81
7	Squirrel Hill North	14.1	151.1	9,274,358	101,400,521	$12,289,909	$86,921,653	$869k	$575k	$1.33	$0.86
8	Bartlett Street	18.1	169.3	11,884,654	113,285,175	$10,340,225	$97,261,878	$570k	$575k	$0.87	$0.86
9	Squirrel Hill South and Greenfield	38.3	207.6	25,124,987	138,410,162	$38,508,116	$135,769,993	$1005k	$654k	$1.53	$0.98
10	Magee Field	12.6	220.2	8,249,556	146,659,718	$12,615,379	$148,385,372	$1003k	$674k	$1.53	$1.01
11	Greenfield School	3.7	223.8	2,414,944	149,074,662	$4,097,153	$152,482,526	$1112k	$681k	$1.70	$1.02
12	Greenfield Avenue	10.1	233.9	6,592,129	155,666,791	$10,751,290	$163,233,815	$1069k	$698k	$1.63	$1.05
13	Irvine Street	6.9	240.8	4,534,552	160,201,343	$3,895,644	$167,129,459	$563k	$694k	$0.86	$1.04
	Total - Estimated[iii]				160,201,343		$167,129,459				$1.04
	Total - Modeled[iv v]		240.8		158,000,000		$167,129,459		$694k		$1.06

i Refers to model-equivalent impervious acres managed.
ii Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%.
iii Estimated using model-equivalent impervious acre to CSO million gallons managed conversion factor of 0.6556 based on SWMM results from 05 April 2019 presentation by Mott MacDonald. Estimated model-equivalent impervious acres use GIS impervious acres to model-equivalent conversion factor of 0.6741. This estimation methodology is explained in Chapter 3.
iv Per 05 April 2019 presentation by Mott MacDonald.
v Estimated and Modeled differ due to a series of rounding errors. The modeled CSO volume removed is 0.01% smaller than the estimate in this memorandum, well within the assumed range of error for the SWMM model. This difference has a negligible impact on the cost per gallon metric.

(green)	Less than or equal to $250,000/imp. acre	(green)	Less than or equal to $0.75/gallon
(orange)	$250,000/imp. acre - $432,000/imp. acre	(orange)	$0.76/gallon - $0.89/gallon
(red)	Greater than $432,000/imp. acre	(red)	Greater than $0.90/gallon

Table 4.6 Sub-catchment Phasing: Highest Class 5 Costs w/ cost-sharing

Cost plus 100% per AACE Class 5 cost estimation precision

#	Area Name	Catchment Imp. Acres Managed[i]	Cumulative Imp. Acres Managed	Catchment CSO Gallons Removed Annually	Cumulative CSO Gallons Removed Annually	Catchment Capital Cost	Cumulative Capital Cost	Catchment Cost per Imp. Acre Managed	Cumulative Cost per Imp. Acre Managed	Catchment Cost per gallon CSO removed	Cumulative Cost per gallon CSO removed
1	Project Catchment Area	59.0	59.0	41,000,000	41,000,000	$16,200,000 [ii]	$16,200,000	$275k	$275k	$0.40	$0.40
2	Phipps Conservatory	0.0	59.0	0	41,000,000	$-	$16,200,000		$275k		$0.40
3	South Oakland	7.3	66.3	4,812,073	45,812,073	$4,668,499	$20,868,499	$636k	$315k	$0.97	$0.46
4	Oakland	40.5	106.9	26,568,627	72,380,700	$20,332,954	$41,201,454	$502k	$386k	$0.77	$0.57
5	Carnegie Mellon	22.0	128.9	14,431,440	86,812,139	$16,640,396	$57,841,850	$756k	$449k	$1.15	$0.67
6	Forbes Avenue	8.1	137.0	5,314,024	92,126,163	$5,325,894	$63,167,744	$657k	$461k	$1.00	$0.69
7	Squirrel Hill North	14.1	151.1	9,274,358	101,400,521	$8,536,309	$71,704,053	$603k	$474k	$0.92	$0.71
8	Bartlett Street	18.1	169.3	11,884,654	113,285,175	$7,423,425	$79,127,478	$410k	$467k	$0.62	$0.70
9	Squirrel Hill South and Greenfield	38.3	207.6	25,124,987	138,410,162	$30,480,916	$109,608,393	$795k	$528k	$1.21	$0.79
10	Magee Field	12.6	220.2	8,249,556	146,659,718	$8,526,779	$118,135,172	$678k	$537k	$1.03	$0.81
11	Greenfield School	3.7	223.8	2,414,944	149,074,662	$3,260,353	$121,395,526	$885k	$542k	$1.35	$0.81
12	Greenfield Avenue	10.1	233.9	6,592,129	155,666,791	$7,879,290	$129,274,815	$784k	$553k	$1.20	$0.83
13	Irvine Street	6.9	240.8	4,534,552	160,201,343	$3,058,844	$132,333,659	$442k	$550k	$0.67	$0.83
	Total - Estimated[iii]				160,201,343		$132,333,659				$0.83
	Total - Modeled[iv v]		240.8		158,000,000		$132,333,659		$550k		$0.84

i Refers to model-equivalent impervious acres managed.

ii Based on CEC's 19 May 2019 Opinion of Cost which is sufficiently detailed for the planning purposes of this document, the Four Mile Run Stormwater Improvement Project is expected to cost $8.1M - $16.2M which is a range of contingencies from -25% to +50%.

iii Estimated using model-equivalent impervious acre to CSO million gallons managed conversion factor of 0.6556 based on SWMM results from 05 April 2019 presentation by Mott MacDonald. Estimated model-equivalent impervious acres use GIS impervious acres to model-equivalent conversion factor of 0.6741. This estimation methodology is explained in Chapter 3.

iv Per 05 April 2019 presentation by Mott MacDonald.

v Estimated and Modeled differ due to a series of rounding errors. The modeled CSO volume removed is 0.01% smaller than the estimate in this memorandum, well within the assumed range of error for the SWMM model. This difference has a negligible impact on the cost per gallon metric.

- Less than or equal to $250,000/imp. acre
- $250,000/imp. acre - $432,000/imp. acre
- Greater than $432,000/imp. acre

- Less than or equal to $0.75/gallon
- $0.76/gallon - $0.89/gallon
- Greater than $0.90/gallon

Summary (continued)

Table 4.7 Flooding Scenarios and Volumes

Per SWMM Modeling by Mott MacDonald

M-29 Flooding Volume (MG)							
Mon River Stage[i]		711			733		
SWMM Scenario		Existing[ii] w/ flap gate[iii]	Core 4MR Project w/ flap gate	Core 4MR Project w/ flap gate and watershed expansion	Existing w/ flap gate	Core 4MR Project w/ flap gate	Core 4MR Project w/ flap gate and watershed expansion
Design Storms	2-Year	2.3	1.7	0.8	3.0	1.8	0.8
	5-Year	4.3	3.3	1.7	7.9	4.6	1.8
	10-Year	6.3	4.9	2.7	12.9	8.4	4.1
	25-Year	9.1	7.4	4.2	21.2	14.6	8.5
	100-Year	20.1	15.8	Not Modeled[iv]	38.8	28.1	Not Modeled[v]

i “Mon River Stage” includes a 711 level (normal pool elevation) and 733 level (FEMA 100-year water surface elevation at the M-29 outfall)

ii Existing conditions represents the current system-wide existing conditions (i.e. 250 MGD WWTP, existing ALCOSAN tunnels, etc.)

iii A potential flap gate could be added to the M-29 outfall. For the model, this means FLAP GATE = YES within SWMM, but it does not include the actual head-loss characteristics of a physical flap gate.

iv The watershed expansion in this memorandum was not simulated with a 100-year design storm.

v The watershed expansion in this memorandum was not simulated with a 100-year design storm.

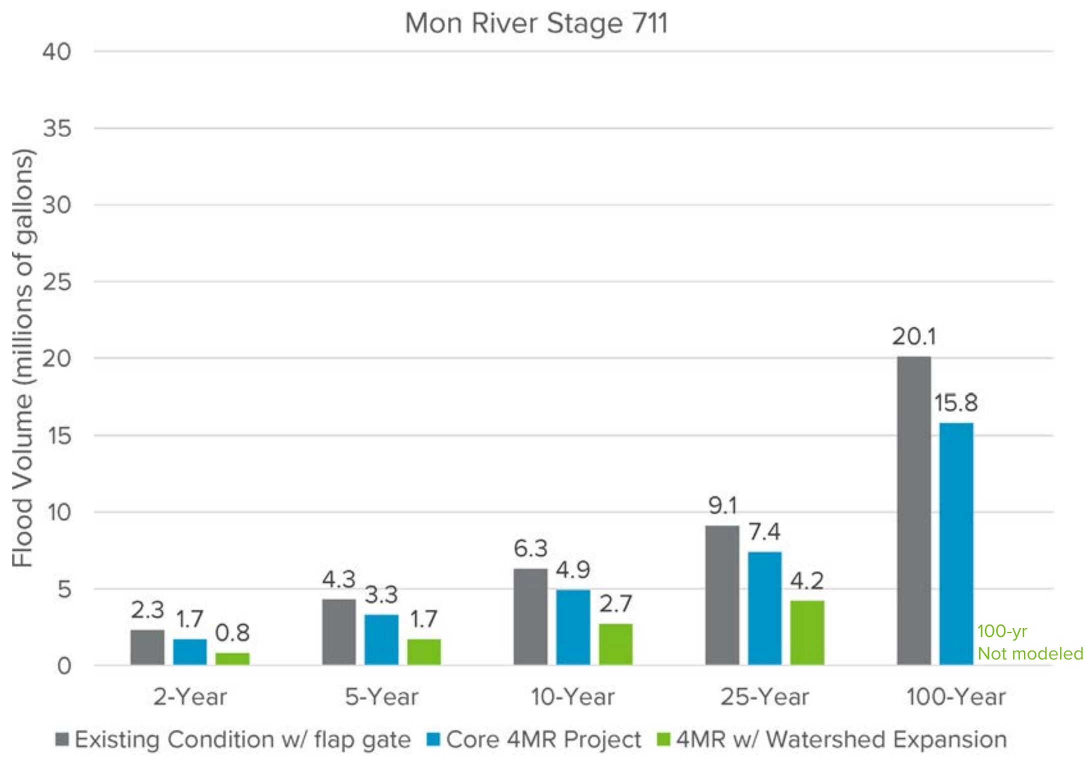


Figure 4.2 Flood volumes under different scenarios at a 711 river stage. Source: 05 April 2019 presentation by Mott MacDonald.

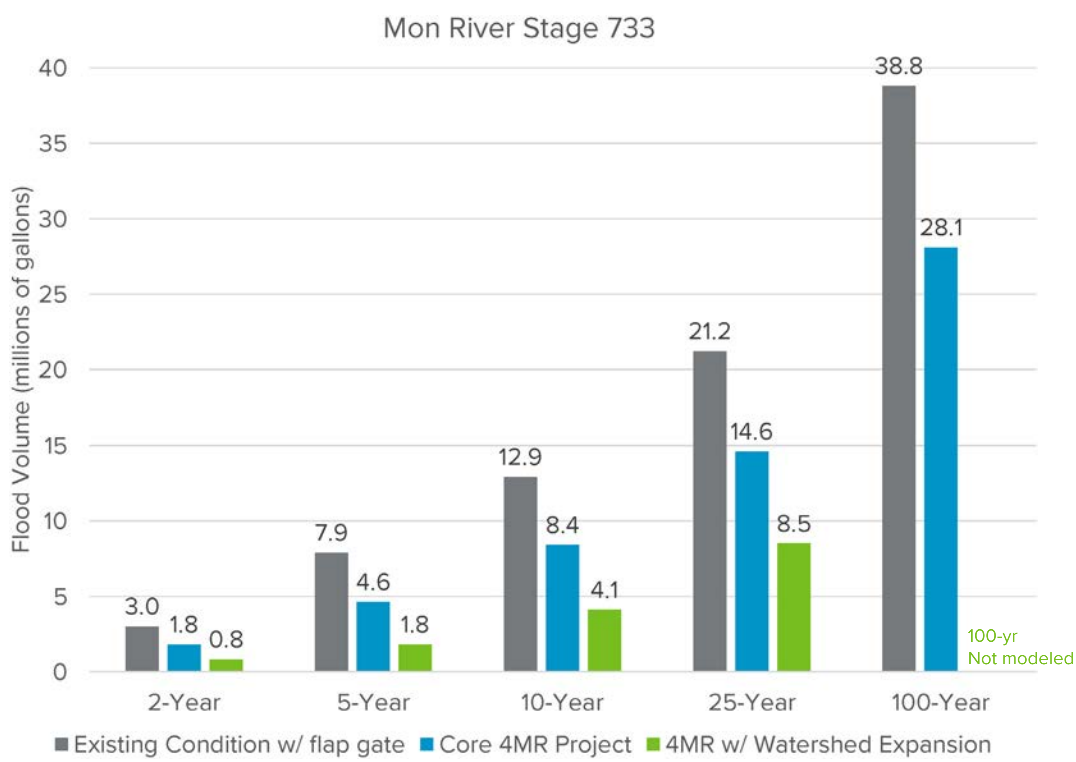
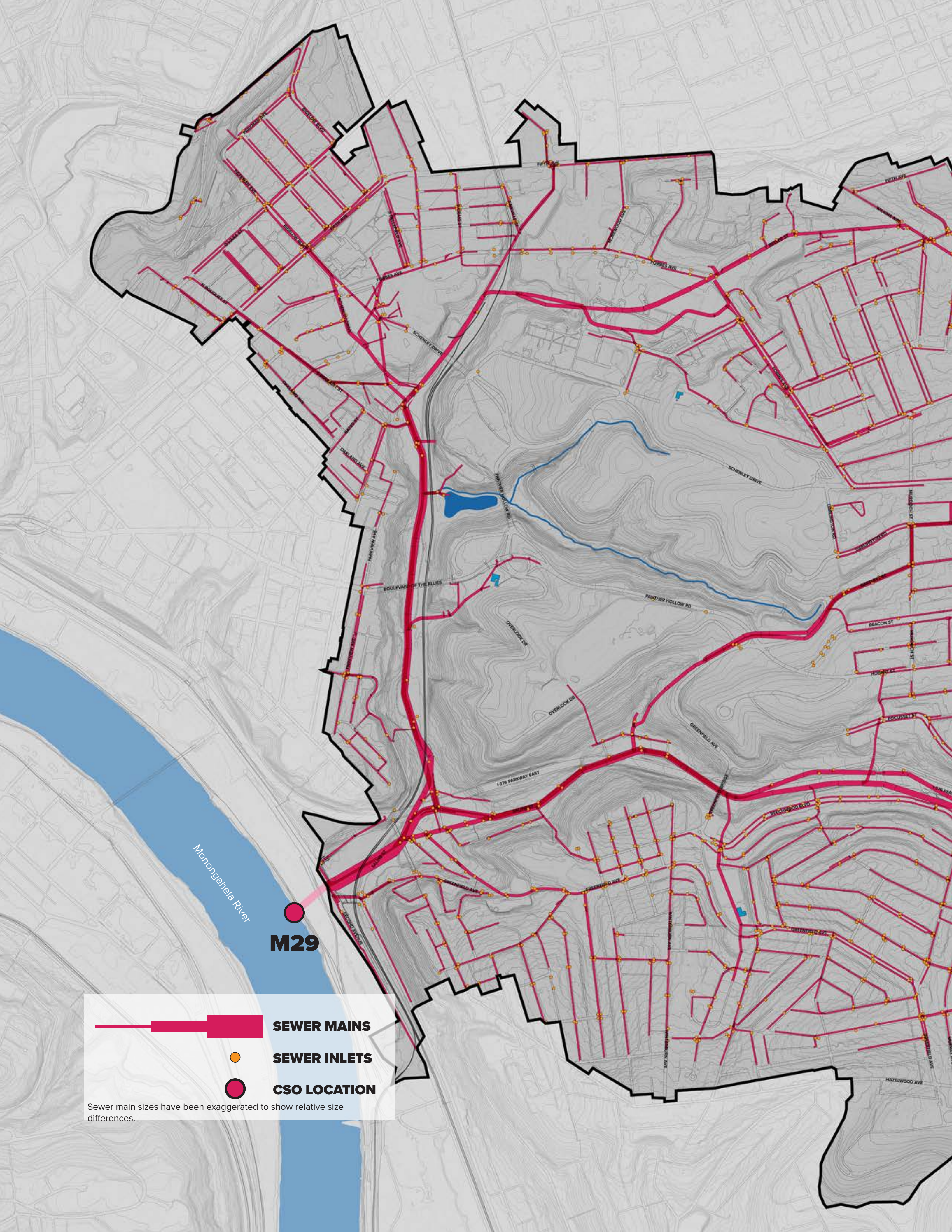


Figure 4.3 Flood volumes under different scenarios at a 733 river stage. Source: 05 April 2019 presentation by Mott MacDonald.


Monongahela River
M29
SEWER MAINS
SEWER INLETS
CSO LOCATION
Sewer main sizes have been exaggerated to show relative size differences.

5

Next Steps

Essential Tasks
Supplemental Tasks

Map of the combined sewer network.

Next Steps

The Four Mile Run Stormwater Improvement Project is the first project of its size since PWSA's 2016 Green First Plan. Pittsburgh's geologic and topographic profile leads to a watershed typology that relies upon major, centralized projects in valleys where stormwater from multiple neighborhoods can be managed. Thus, the large centralized projects must be planned in coordination with upstream projects in order to justify a larger upfront cost.

In M-29 Four Mile Run, the opportunities for capture, detention, and conveyance are largely limited to what can be constructed within the right-of-ways. The neighborhoods are largely built-out and have few open spaces for standalone detention and conveyance projects. This memo estimates cost and performance that is possible in the upper areas of M-29. This analysis shows a favorable ratio of cost versus performance but the level of detail is not sufficient for implementation. The Watershed Expansion Team thus recommends the following methodology for an Infrastructure Development Plan that comprehensively evaluates right-of-way needs and opportunities for stormwater in M-29.

This proposed methodology has seven essential tasks with some suggested additional tasks that can add value to PWSA's stormwater strategy city-wide. The outcomes should be to:

1. Green design concept for each sub-shed, up to 10% design
2. Identify implementable sub-shed project packages
3. Generate refined cost and performance estimates for each sub-shed project package
4. Summarize a refined cost and performance estimate for the M29 complete network development

Essential Task 1: Hydrological demand analysis

In order to understand the potential impacts of the proposed watershed expansion efforts for Four Mile Run, it is important to assess the overall demand for networked stormwater conveyance and detention at the block-by-block level, throughout the sewershed. The Watershed Expansion Team will leverage the existing SWMM models developed by Mott MacDonald, as well as previous watershed expansion work by this team, to develop a meaningful understanding of flow inputs at each inlet or catch basin within the select project areas, as well as within long runs of street gutter. This Task will progress logically, focused first on areas that represent the highest impact potential to the overall Four Mile Run project, as well as the "low hanging fruit" - easy to disconnect watersheds with potentially lower costs to implement. This Task is closely aligned with Task 2 below, and will likely progress concurrently or in rapid succession.

As mentioned above, this work will use previous SWMM modeling efforts by Mott MacDonald as the basis for new modeling efforts, focused on individual sub-catchments within the larger M29 sewershed. The sub-catchments will be first extracted from the larger SWMM model, and all connections to the SWMM pipe model will be converted to outlet nodes for simplicity, with capture efficiencies and bypass node connectivity maintained. Next, these sub-catchments will be further split, if needed, to account for inlets that were not represented in the larger model, as well as where gutter length between inlet nodes is substantial enough to warrant a finer resolution analysis. The end product of Task 1 is essentially a finer resolution SWMM model, focusing primarily on hydrology and development of a surface conveyance network model under existing conditions. One such model would be developed for each sub-watershed that may be later disconnected from the PWSA system to the Four Mile Run conveyance infrastructure downstream.

Essential Task 2: Existing street and curb capacity analysis

Based on our early watershed expansion work, the Watershed Expansion Team feels that a green street, conveyance-based approach is likely going to be cost effective for this project. However, we also acknowledge that these types of conveyance strategies are largely dependent upon existing gutter capacities, street widths, and road geometries, and that at some point more substantial improvements (enhanced gutters, bioswales, and storm pipe networks) will be needed to convey stormwater to downstream reaches. To ensure that efficient, cost effective solutions are derived in later iterations, the Watershed Expansion Team will evaluate the existing surface conveyance capacity of each block, focusing on existing, networked gutter flow capacities as a primary driver of design. The intent would be to evaluate these conveyance capacities specifically for the 1.5", 6-hour design storm, knowing that these gutters were originally designed for much larger storms per roadway design requirements. Alternately, these analyses could be run for the full Typical Year (2003) to ultimately demonstrate regulatory compliance.

The existing capacity analyses described above would be based on a set of predefined Design Goals, acceptable to PWSA and the various City departments - specifically City Planning, DOMI, and DPW. This important precursor step would ensure that subsequent design flows in right-of-ways are not too deep, not too wide, and not too fast for maintaining public health and safety. The proposed design parameters to be discussed include maximum flow depths in gutters, maximum gutter spread, and maximum flow velocities, specifically for the 1.5", 6-hour design storm or the largest storm event in the 2003 Typical Year.

The Watershed Expansion Team would initiate this task by means of convening a meeting of key stakeholders - PWSA, City Planning, DOMI, and DPW - in order to discuss the overall strategy and ultimately obtain agreement on the specific Design Goals. The intent of this ongoing dialogue would be to not only evaluate what existing curb and gutter performance standards should but what future standards should be, as well. Currently the City has approved standards details for both 4" and 7" deep curbs, without gutters. PWSA has an interest in exploring a new curb standard than include provisions for combination curb and gutters, poured monolithically in order to ensure that future paving efforts do not inadvertently reduce gutter capacity, as they have in the past. Reconciling these design preferences and establishing new protocols within the City for edge milling existing roads where gutter capacities have been diminished over time due to lax paving practices is critical to the success of this project overall.

Once these Design Goals are established, the team will work to incorporate existing gutter geometries into Task 1 SWMM models. Doing so will require a combination of desktop terrain analysis to derive longitudinal road slopes and widths, and to confirm overall network connectivity, as well as field survey work to evaluate existing curb heights and road cross-slopes. This field survey work would employ conventional means of measuring, curb heights in spot locations and evaluating cross-slopes based on simple spot surveying. However, a much more innovative and potentially useful approach is outlined as an optional add-on service. In this alternative approach, the Design Team would work closely with a technology sub-consultant, Landbase Systems or CivicMapper, to systematically collect roadway data points in a dense mesh cloud, and automatically extract pertinent modeling information. A more detailed description of these effort is described in Supplemental Task 2, later in this proposal.

Once the proper conveyance geometries are incorporated into the SWMM models, the Design Team will have a solid sense of where existing gutters may already be adequate for disconnection of smaller, CSO-focused storm events, and where improvements to the overall conveyance network may ultimately be needed.

Next Steps (continued)

Essential Task 3: Assessment of potential street and curb capacity

Built on the outcomes of Task 2, Task 3 begins development of a technical "kit-of-parts" for cost-effectively integrating green infrastructure conveyance and storage elements in the urban fabric of the City. This idea is explored later in this proposal as an add-on service to PWSA, with City-wide applicability. However, the intent for Task 3 would be to develop the individual kit-of-part strategies that apply specifically to the Four Mile Run project. In general, the kit-of-parts would include inlet bypass, conveyance, storage, and conflict resolution strategies.

With the standards and kit-of-parts as guides, the Design Team would integrate these design patterns into the SWMM models, as a means of boosting existing gutter capacities in a deliberate, measurable, and cost effective way. The goal would be to responsibly disconnect as much of the watershed as possible, by strategically and systematically enhancing conveyance and providing attenuation as needed, along the way.

The following are the types of typologies that would be further explored and developed into repeatable, well-defined design strategies. In general, these typologies would be identified, then evaluated with project partners with regard to feasibility of construction, cost effectiveness, maintenance, and similar. If deemed to be acceptable, further development of these concepts would occur to standardize construction detailing, cost considerations, and applicable SWMM modeling techniques. Once established, these techniques would be directly implemented into the ongoing SWMM modeling efforts.

Inlet Bypass Strategies:

Inlet bypass strategies include any design elements that specifically allow smaller CSO-focused storm runoff to bypass the combined sewer system, while allowing larger storms to drain directly to the sewers to minimize downstream flooding risks. These include:

- Utilizing PWSA standard "dual trap inlets", or similar flow splitting control structures.
- Employing "green inlets" to offer direct connection of public right-of-way runoff to immediately adjacent green spaces.

Developing standards for "inlet bypass bump-outs", which can be inexpensively retrofitted to existing catch basin and road sections. These types of bump-out are effectively flow-through devices with integral flow restricting outlet weirs. When the weir capacity is exceeded, surcharged runoff drains back into the existing inlet, rather than be conveyed downstream.

Exploring other means of bypassing existing catch basins and inlets, based on published work in other cities. For example, eDesign Dynamics - a partner on this team - recently developed a standards manual for Newburgh, New York that employed a similar concept called "Street Creeks" and included associated design details.

Conveyance Strategies:

Currently, stormwater runoff throughout the City is conveyed via existing, seldom maintained gutters and legacy pipe networks. Other strategies to be explored include:

- Improving maintaining protocols for existing gutters, if they already provide adequate flow capacity given the hydrologic demand.
- Edge milling of existing roads with over-paved gutters, where needed to provide added flow capacity based on model results.

- Providing new concrete combination curb and gutters, either as an alternative to edge milling or as a more intentional implementation to prevent future over-paving.
- Constructing new bioswales, outside of the cartway and sidewalks, and direct street runoff to these new green infrastructure facilities.
- Constructing new green gutters, curbed bump-outs, or networked tree pits to provide more structural conveyance within public right-of-ways.
- Development of new separate storm sewer systems.
- Development of new sanitary only sewer systems, with the intent of converting the existing combined sewer pipe network to a separate system.

Storage Strategies:

Storage strategies - rain gardens, porous pavement, bioswales, etc. - are already well-documented within the PA DEP Best Management Practices Manual for Stormwater Management, and similar published sources. This proposal would effectively apply these known patterns to the Four Mile Run study area, as part of Task 4 below. Additional consideration and documentation may be given to sediment and debris management, as part of this process.

Conflict Resolution Strategies:

Last but not least, urban green infrastructure design and implementation is often in physical conflict with existing underground and aboveground utilities, service laterals / connections, ADA pedestrian routes, and existing features, such as mailbox, signage, and trees. A better understanding of the complexities and cost considerations of resolving these conflicts would greatly benefit the overall project.

Essential Task 4: Identification of flow-attenuation sites and urban design recommendations

Based on the delta between the hydrological demand (Task 1) and the assessed conveyance capacity (Task 2), Task 4 would work to identify feasible locations within the sub-catchments in which flow could be attenuated by the thoughtful, targeted placement of green (or gray) infrastructure storage nodes. Ideally, these locations would be within public spaces or adjacent to right-of-ways, as has been historically the case in Pittsburgh's green infrastructure efforts in the past. However, by aligning the storage node placement with known conveyance limitations and hydrological demand, we are proposing a more intentional planning effort that would not preclude non-conventional storage solutions. Vacant and underutilized private lands, institutional spaces at school, university, and hospitals, public / private parking lots, and storage under roadways would be reasonable to consider for future design, if the hydrologic demand and conveyance limits ultimately dictate.

It is worth noting here that the driving forces behind Tasks 1 and 4 are to: (a) maximize the overall quantity of runoff that is removed from the PWSA system and redirected to the Four Mile Run conveyance infrastructure; and (b) do so in such a way that acknowledges the conveyance limitations within the Four Mile Run project, so as to not direct more flow to the system than it is able to safely handle. With proper flow attenuation, larger areas can ultimately be disconnected from upland sub-catchments to the Four Mile Run conveyance network.

The SWMM models developed in previous tasks would be amended to include generic storage nodes in those locations where the hydrologic demand exceeds the existing gutter capacity. Based on the actual site constraints, one of more Storage Strategies from Task 3 would be identified, and incorporated into the ongoing SWMM modeling efforts. Because there are a number of potential strategies that may be employed for any given storage or conveyance node, Task 5 below provides an innovative and useful methodology for rapidly iterating these combinations to determine the most desirable solution set.

Next Steps (continued)

Essential Task 5: Rapid system prototyping to optimize network cost and performance

One of the core challenges of taking a kit-of-parts approach to planning watershed scale green infrastructure is that the solution space tends to be large, complex, and indeterminate. In other words, there are many possible combinations of stormwater capture, conveyance, and storage solutions, and it is therefore very difficult to derive a near-optimal solution, without time-consuming iteration and effort. To address this challenge, the Design Team proposes a novel approach, utilizing an artificial intelligence technique known as a “genetic algorithm” for rapid system prototyping and optimization of cost efficiency.

Originally developed in 1975 by mathematician John Holland, a genetic algorithm is an adaptive search and optimization process, based on the principles of natural genetics, genetic diversity, and natural selection (survival of the fittest). The applicability to the Four Mile Run project is in our need to optimize the overall cost effectiveness of the proposed green infrastructure interventions - an ideal use case for genetic algorithms. As the Design Team can demonstrate, we have already developed methodologies and a stable, functional software prototype to effectively encode SWMM models as if they are living organisms, replicate these organism as a diverse “population” of individuals, “evolve” these individuals over numerous generations, and pluck from the results the “most fit” individual. This most fit individual represents the most cost-efficient engineering solution for the Four Mile Run project, that also meet the functional constraints of the project - in particular, acceptable level of service for flooding at vary points in the system. The software output includes an actual working SWMM model, cost estimate report, and performance assessment ($ / gallon removed) as verifiable end products of the process.

Explanation of the background, methodology, and applicability of the proposed genetic approach to SWMM model optimization is best left to an in-person presentation and live demonstration of the working software prototype. These materials have already been developed and the Design Team is able to present to PWSA at your earlier convenience. We recommend that at least one hour be set aside for the presentation, demonstration, and discussion of the concept.

Essential Task 6: Shed-wide Infrastructure Development Plan (IDP)

Following this analysis, the team will identify and summarize the most effective and timely project packages that PWSA should pursue within M-29. These project packages, which will take into account opportunities that are aligned with projects by other agencies, will comprise the shed-wide Infrastructure Development Plan. The IDP will be PWSA’s road-map for when and how project packages should be procured within the shed for cost-effective implementation.

Essential Task 7: SWMM Model Simulation to validate system performance

The Infrastructure Development Plan would then be integrated into the latest SWMM model for M-29 and simulated both to ensure local performance requirements are met and to provide a detailed estimate of CSO reduction when included in the system-wide SWMM analysis.

Supplemental Task 1a: Kit of parts technical development (to 60% design)

The success of the core project is predicated upon the success of green stormwater management strategies (i.e.: networked conveyance and detention) within the rights-of-way in the contributing upper shed, as well as a vivid understanding of the costs and possible extents of the proposed interventions. These costs, footprints and practice depths are contingent upon agreement between PWSA, DOMI, DCP and DPW (and possibly others) regarding the set of acceptable practices, dimensions and construction specifications, and must be demonstrated to fit within existing constraints ranging from private property concerns to buried utilities. Any plan to utilize the ROW will be highly dependent an understanding of likely costs and expected performance of GSI components, both of which are not currently established in Pittsburgh. If decisions are to be made based on these parameters, then greater detail is needed along with preliminary feedback from relevant agencies.

A robust set of policies and practices shall be outlined in a technical kit-of-parts that provides 60% design details of GSI components that can be applied at scale in rights-of-way, and that can be assembled into functioning alternatives for delivery of contributing runoff to points of connection with the proposed park drainage system.

BMPs and related details to be developed to address the following:

- Standard utility conflict scenarios
- Including offsets, utility stacking, design standards, alternatives
- Green inlets
- For removal of sediments prior to introduction to green practices
- Street crossings
- Overland or within trench drains or pipes
- Curb/gutter replacement standards and designs
- Roadway sections for both pervious and impervious pavements
- Downspout disconnection strategies
- Including connections with GSI
- Discharges to curb reveal/ROW
- ADA compliance
- Tree pits, bump-outs and bioswales
- Subsurface storage and connections
- Overflows and low-flow regulators
- Including peak flow returns to the combined sewers
- Foundation offsets and treatment of service laterals
- Green alleys
- French drains or under-drains
- Inspection ports and clean-outs
- Soil and porous media specifications

The team will consider the complete range of GSI practices already employed and/or approved for use in the city, and will review design precedents and guidelines from other regions. Where possible we will modify existing designs and details for general application, or will otherwise develop new (60%) design details and specifications.

We will develop fabrication and installation cost estimates for each GSI component and or procedure, and assemble a costing table that allows for easy re-assessment of project alternatives.

We will develop sketches of an assembled network that delivers runoff to a point of collection given best available data for existing land elevations, trees, structures and utilities.

The team will deliver 60% design details with cost estimates for component parts and performance estimates for the assembled networks, submitted as part of a larger deliverable, not a standalone design manual. We will also investigate and report case studies demonstrating successful applications of these techniques.

Next Steps (continued)

Supplemental Task 1b: Kit of parts city and institutional outreach

We will lead an iterative outreach effort to relevant agencies (DOMI, DPW, DCP, and others as needed) to discuss the nature and specifics of networked interventions and their implications for the ROW. The intent is to provide a fleshed-out set of standards and designs that can be replicated throughout the city, and realistic costs associated with fabrication and installation of component parts.

We will also initiate conversations with utility providers and owners of sub-surface structures to understand their concerns and requirements for utility conflict and offsets, and develop a relevant set of cost estimates for preferred resolutions.

Supplemental Task 1c: Kit of parts SWMM templates and Green SWMM model guidance

As part of the earlier Task 3, the Design Team would work with PWSA and the City to formalize a series of standard construction details and unit cost estimates for whichever strategies make the most sense for the Four Mile Run watershed expansion efforts. Task 1a and 1b above expand upon that work, with the intent on developing and formalizing a more expansive set of design guidance and policy engagement points, which have applicability to the larger PWSA service area. This new Task 1c, by comparison, builds upon these earlier efforts to create a separate guidance document, specifically for SWMM modeling of urban green infrastructure. The end user would be PWSA and its engineering sub-consultants, with a goal of working towards predictability and consistency across PWSA capital improvement projects related to green infrastructure and stormwater management. Overall, this document would provide working examples of SWMM best practices and PWSA-approved techniques for modeling complex structures such as dual trap inlets, cascading planter beds in the right-of-way, bioswales, and multi-layer storage nodes such as a rain garden with underground storage below. It is not intended to be prescriptive, however, given that special conditions and engineering judgment often override standard details and best practices.

Supplemental Task 2: Focus Area Proof-of-Concept Data Collection

As mentioned previously, some level of field survey work is required for the proposed work, in order to obtain critical modeling data related to physical infrastructure geometries, not easily captured in a desktop analysis. As an add-on service to this proposal, the Design Team would collect this data at a much higher resolution than conventional survey allows, and potentially much faster and more accurately, utilizing technology-based solutions developed by local technology firms, Landbase Systems and CivicMapper. The Design Team would solicit proposals from these firms to systematically collect roadway data points in a dense mesh cloud, and automatically extract the following pertinent modeling information.

- Existing curb heights, as well as top and bottom of curb elevations.
- Road cross slopes and crown elevations
- Ground-truthed Inlet and catch basin locations and localized sag geometries, at a much higher level of confidence than existing GIS datasets, curated by PWSA.
- Locations of flow departure from the designed roadway storm collection network, due to irregular terrain, intercepting driveways, and similar. Typically, these flow departure conditions are ignored in urban hydrologic analyses, but in reality they can pose very significant differences between anticipated and actual flow conditions.

From the data collected above, the overall gutter geometry from top of curb to road crown can be evaluated, for understanding the full hydraulic conveyance capacity of individual road segments throughout the study area. In addition, the dense terrain data can be used to inform, validate, and augment existing sub-catchment boundaries without PWSA SWMM modeling efforts, if proper due-diligence is performed to incorporate the new gutter lines and road crowns in the analytic hydrologic surface model.

In addition to informing SWMM modeling, the above proof-of-concept work would potentially have a second added value to PWSA and to the City. By collecting a visual 3D model of the roadway within the project area, this work could be used to identify and assess areas of deterioration or damage along curbs, sidewalks and roadway surfaces, including alligator cracking, potholes, damage from vehicles, and other structural deficiencies. Such data could then be leveraged to evaluate whether the City should consider immediate investment in the road or pedestrian infrastructure, which in turn could be used to offset new green infrastructure investments by PWSA in that same area. Alternately, this same data could be used to estimate remaining service life of roads, curbs, and sidewalks, instead of simply evaluating whether replacement is imminently needed, in a binary yes-or-no fashion. The concept of remaining service life would provide a new and potentially transformative cost-sharing framework for PWSA and the City to co-invest in green street projects throughout the City. If, for example, PWSA needs to replace an entire sidewalk to incorporate green infrastructure in a high-impact area, and the sidewalk had a reasonable remaining service life of 5 years, then PWSA would theoretically agree to pay only for the lost service life, rather than the entire cost of the new sidewalk. The City would pay the balance of the 20-year service life of the sidewalk, or 75% of the overall construction costs.

Supplemental Task 3: Advanced Triple Bottom Line (TBL) Cost-Benefit Analysis and Cost-Sharing Opportunity Report

The team will develop a triple bottom line assessment to compare implementation and operational costs with multiple benefit streams relevant to upstream separation practices developed in Supplemental Tasks 1a and 1b above. Various benefit streams have been demonstrated to result from the use of green systems, which are expected to address the obligations and priorities of other agencies, authorities and non-profits in the region. In some cases, construction of a BMP can be performed as part of a scheduled upgrade or replacement of public (or private) infrastructure. In other cases, an incremental enhancement to a BMP can provide additional benefits at an incremental cost. As PWSA has neither the authority nor the mandate to deliver these benefits, they are frequently hesitant to incur the cost and responsibility for components of features that do not contribute to the stormwater function of the BMP. To better understand the allocation of benefits, the team will identify services that might ordinarily (or occasionally) receive funding from other sources, and quantify the added values that can result from the use of green practices as they might align with those funding sources. A short list of those benefits includes:

- Transportation improvements
- Improved accessibility
- Improved public safety and reduced crime
- Property value increases
- Reduction of urban heat island effect
- Workforce development and job creation
- Improved air quality
- Recreational and educational opportunities

In some cases the benefits will include diminished maintenance (such as use of pervious street pavers in place of asphalt), and in other cases might include construction of entirely new public assets such as parks and trails, bicycle lanes and improved pedestrian crossings. The team will assemble a TBL analysis and Life-cycle Cost Analysis (LCCA) within Autocase (or other software preferred by PWSA), and map the resulting benefits to the priorities of potential cost-sharing partners, thus providing a basis for PWSA to approach other funding sources for cooperative agreements. The team will present the information in a report.

Next Steps (continued)

Supplemental Task 4: Microshed Engagement

As sites are identified for intervention and storm separation, the team will approach residents and other stakeholders to discuss the range of opportunities that exist to prevent runoff from entering the sewer system and safely conveying to common points of collection. We will discuss the need for stormwater improvements and the science behind green practices, and explain the extent to which property owners will need to collaborate to meet the site's performance needs. Through some innovative game-playing and design tools, we will work with residents to configure interventions in a manner that is consistent with their priorities and sensibilities, and elicits on-going support and appreciation of new drainage paradigms. Our team-members' experiences, and the published experiences from across the country, is that GSI within developed areas is far more difficult to sustain without local buy-in and approval. By ignoring this crucial process, PWSA runs the risk of losing expensive practices to vandalism, misuse, and even rogue modifications that reduce performance and create new hazards. Just as residents love and appreciate street trees, they will also learn to appreciate bioswales, bump-outs and green gutters, along with the satisfaction that comes from participation in the design process.

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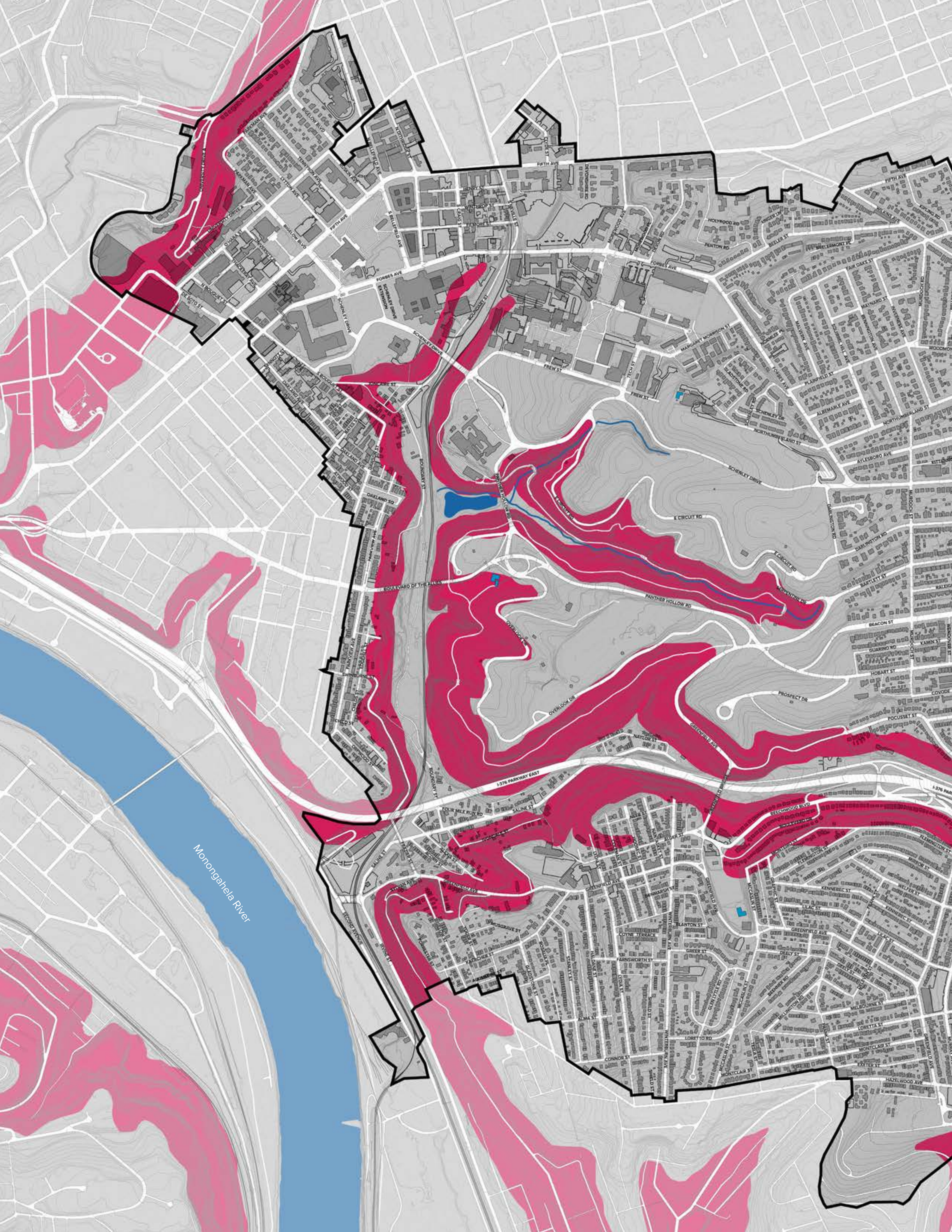


Monongahela River
FIFTH AVE
FORBES AVE
SCHENLEY DRIVE
FREW ST
MARGARET MORRISON ST
SCHENLEY DRIVE
E CIRCUIT RD
PANTHER HOLLOW RD
BOULEVARD OF THE ALLIES
OVERLOOK DR
BEACON ST
HOBART ST
PROSPECT DR
GREENFIELD AVE
I-376 PARKWAY EAST
BEECHWOOD BLVD
HAZELWOOD AVE

A

Appendix

A.1 Controlling Peak Flows

Map of landslide-prone slopes.

A.1 Controlling Peak Flows

The design of stream and detention systems within the Four Mile Run conveyance network requires a reasonably refined understanding of the contributing flows reaching each segment during wet weather, specifically with respect to the peak flows expected during extreme events. The estimates of these peak flows are performed for the upper contributing watershed areas given terrain, land cover, and time of concentration. The stream designers will look at the full range of both wet and dry weather flows within each stream segment, and configure the stream geometry and materials to provide habitat and aesthetic value during dry weather while also safely receiving and conveying peak flows without suffering damage.

Due to the wide range of rain events experienced in this region, combined with the "flashiness" of the urban contributing sub-catchment areas, the difference between peak and base flows is expected to be very large, which introduces challenges to successful stream design, and limits the full potential extent of expansion plans. To best address these limitations, a performance comparison of two different scenarios was prepared.

If we presume that the peak volumetric flow rate conveyance capacity of a stable stream channel segment is less than the peak runoff rates expected to be generated by the urban watershed that was historically tributary to that segment, we could be presented with a choice between:

1) conveying all storms from a portion of the historic watershed, or

2) capturing a portion of all storms from the entire historic watershed

The second option is possible, because in the majority of sub-catchment areas the existing combined sewers presumably have capacity to serve as a secondary stormwater conveyance for excessive stormwater as they currently are the primary stormwater conveyance for all stormwater. In this scenario, excess stormwater is diverted to it only when the peak rate exceeds the established threshold rate during the most intense storm events. Both options deliver the same peak flow rate to the stream, but the resulting volume of stormwater ultimately removed from the combined sewer is significantly greater under the second scenario.

To illustrate the differences, two hypothetical hydrographs for flows entering the stream system resulting from a 1.5-inch rainfall event were generated. This is a highly generalized event and generalized catchment configured to explain the differences in the scenarios. Base flow in the stream was ignored since we are looking at fluctuations in flow. Typically, modeled hydrographs are generated from precipitation data applied to a modeled landscape with known dimensions, such as size, slope, land cover and time of concentration. To avoid this process, we simply created a reasonable hydrograph which peaks at 10 cfs, and assumed an overall runoff coefficient of 0.6. The area under the curve is the total volume of runoff generated by the storm event. We use that total volume to back calculate the extent of the contributing area corresponding with these conditions.

The exercise continues as follows: We will assume that the hypothetical catchment consists of an area covering 66 acres. The limitation suggests that only 40 acres can be “disconnected” from the sewer system and made to flow toward the park. Under this scenario, 26 acres will remain connected to the combined sewers and will thus contribute to overflows. The table below describes the performance of this portion of the system during the hypothetical 1.5-inch storm:

A.1 Controlling Peak Flows (continued)

INDIVIDUAL RAIN EVENT SCENARIO 1

Rain event total depth (in)	1.5
Peak flow-rate (cfs)	10
Area diverted to park (acres)	40
Area diverted to sewers (acres)	26
Event volume managed in park(cf)	130,000
Event overflow volume (cf)	86,700
Percent of event managed	60%

This event is also illustrated by the first two hydrographs on the next spread. In the alternate scenario, all 66 acres of the contributing catchment are separated and made to flow toward the park. However, a flow control device (or many distributed devices) restricts the peak flow contributions from the 66 acres to only 10 cfs, with the remainder diverted back to the combined sewer system where it will contribute to overflows. Under this scenario, a larger number of events will generate runoff at the peak capacity of the receiving system, but the total depth of rainfall managed is less. The system manages more events and receives runoff from a larger area, but with fluctuations in the same range as the first scenario.

INDIVIDUAL RAIN EVENT SCENARIO 2

Rain event total depth (in)	1.5
Peak flow-rate (cfs)	10
Area diverted to park (acres)	66
Area diverted to sewers (acres)	0
Event volume managed in park (cf)	171,200
Event overflow volume (cf)	45,500
Percent of event managed	79%

On a per event basis, Scenario 2 manages 32% more volume than Scenario 1, and the equivalent rainfall depth managed by Scenario 2 is 1.2 inches over the entire 66 acre drainage area.

To estimate annual performance of each scenario, we proceed with the assumptions that we will receive 40 inches of rainfall in the year. By analysis of Pittsburgh rainfall data, 90% of all rainfall comes in events of 1.5 inches or less, and 80% of all rainfall comes in events of 1.2 inches or less. For the 20% of rain events that exceed 1.2 inches, we assume that in Scenario 2 half of the event will reach the park and half will be diverted to the sewers.

ANNUAL PERFORMANCE ESTIMATE SCENARIO 1

Percent rainfall from events 1.5 inches or less	90%
Annual total runoff volume (from 66 acres) (cf)	5,750,000
Annual volume managed in park (from 40 acres) (cf)	3,424,000
Annual overflow volume (from 26 acres) (cf)	2,326,00
Percent of annual runoff managed	60%

ANNUAL PERFORMANCE ESTIMATE SCENARIO 2

Percent rainfall from events 1.5 inches or less	80%
Annual total runoff volume (from 66 acres) (cf)	5,750,000
Annual volume managed in park (from 66 acres) (cf)	5,031,000
Annual overflow volume (cf)	719,000
Percent of annual runoff managed	88%

Scenario 2, therefore, manages 47% more runoff on an annual basis than Scenario 1, while still restricting peak flows through the system to 10 cfs. There are several simplifications that go into elaborating this performance model, which is intended as an illustration only. For example, rainfall intensity and time of concentration govern flow rates, but an analysis based on intensity would be more complex and require more detailed inputs. The result, however, should be valid on general terms.

A.1 Controlling Peak Flows (continued)

SAMPLE SCENARIO ONE (40 OF 66 ACRES IS MANAGED IN PARK)

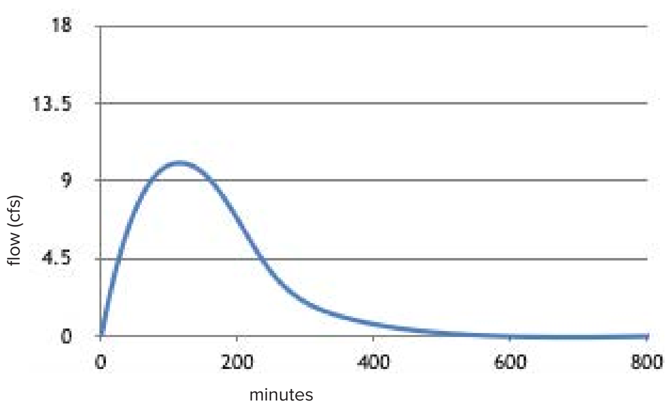
INDIVIDUAL 1.5 INCH RAINFALL EVENT

• SUB-CATCHMENT AREA COVERS	66 ACRES
• OVERALL RUNOFF COEFFICIENT =	0.6
• PEAK MANAGEABLE FLOW =	10 CFS
• AREA DIVERTED TOWARD PARK =	40 ACRES
• AREA DIVERTED TOWARD SEWERS =	26 ACRES
• EVENT TOTAL RUNOFF VOLUME =	216,700 CF
• EVENT VOLUME MANAGED IN PARK =	130,000 CF
• EVENT OVERFLOW VOLUME =	86,700 CF
• PERCENT OF RUNOFF MANAGED =	60%

ANNUAL PERFORMANCE ESTIMATE

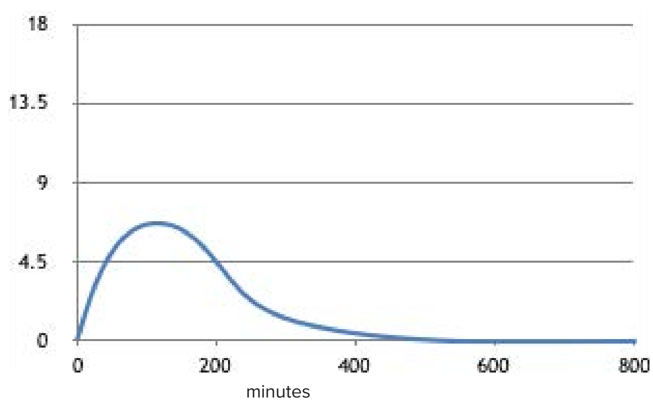
• ANNUAL RAINFALL =	40 INCHES
• ANNUAL TOTAL RUNOFF VOLUME (from 66 acres) =	5.7 MCF
• ANNUAL VOLUME MANAGED IN PARK (from 40 acres) =	3.4 MCF
• ANNUAL OVERFLOW VOLUME (from 26 acres) =	2.3 MCF
• PERCENT OF ANNUAL RUNOFF MANAGED =	60%

Runoff Hydrograph for 40 acres (managed in the park)



Total Volume: 130,000 CF

Runoff Hydrograph for 26 acres (diverted to sewer)



Total Volume: 86,700 CF

SAMPLE SCENARIO TWO (RUNOFF FROM 66 ACRES MANAGED UP TO 10 CFS)

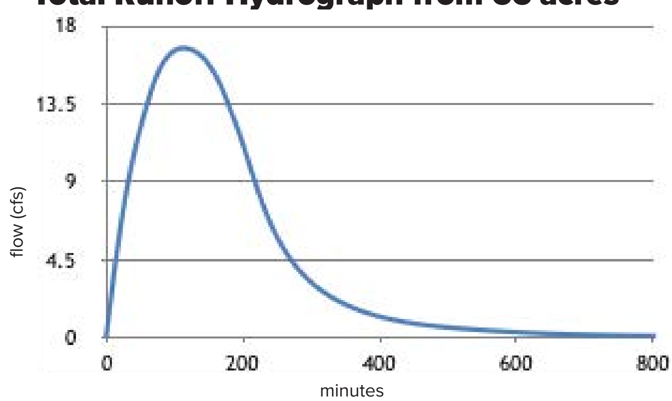
INDIVIDUAL 1.5 INCH RAINFALL EVENT

• EVENT TOTAL RUNOFF VOLUME =	216,700 CF
• EVENT VOLUME MANAGED IN PARK =	171,200 CF
• EVENT OVERFLOW VOLUME =	45,500 CF
• PERCENT OF RUNOFF MANAGED =	79%

ANNUAL PERFORMANCE ESTIMATE

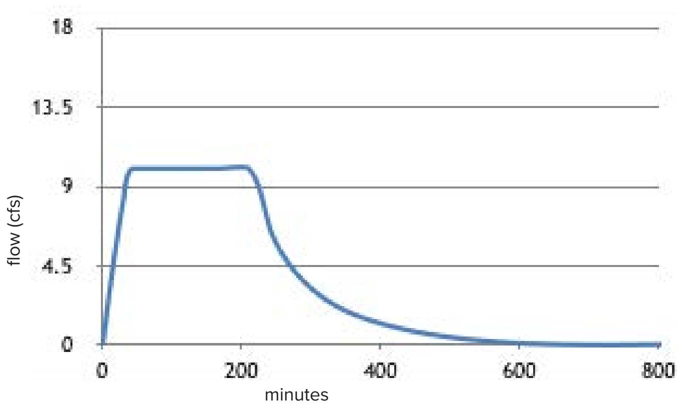
• ANNUAL TOTAL RUNOFF VOLUME (from 66 acres) =	5.7 MCF
• ANNUAL VOLUME MANAGED IN PARK =	5.0 MCF
• ANNUAL OVERFLOW VOLUME =	0.7 MCF
• PERCENT OF ANNUAL RUNOFF MANAGED =	88%

Total Runoff Hydrograph from 66 acres



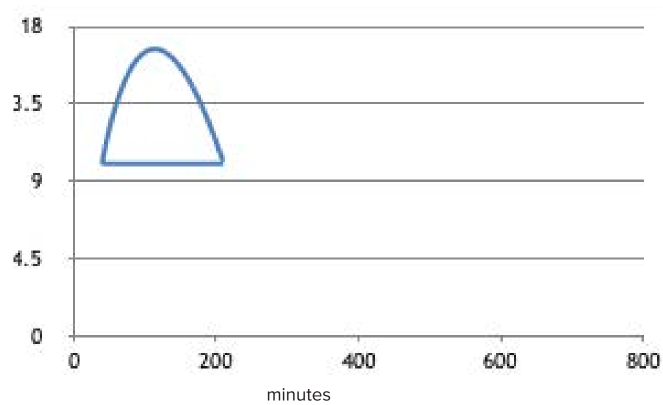
Total Volume: 216,700 CF

Runoff Hydrograph for 66 acres cut-off at 10 cfs (managed in the park)



Total Volume: 171,200 CF

Excess Runoff Hydrograph for 66 acres (diverted to sewer)



Total Volume: 45,500 CF

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